STATE LIBRARY OF PENNSYLVANIA
3 0144 00264180 1

PLEISTOCENE TERRACES
OF THE
SUSQUEHANNA RIVER
PENNSYLVANIA

PELTIER

PYG 345/4.3
CLASS P~~38.1~~2 BOOK ~~13~~

VOLUME G 23
c. 1

PENNSYLVANIA
STATE LIBRARY

PENNSYLVANIA STATE LIBRARY
General Library Bureau
Government Publications

PYG 345/4.
G 23
c. 1

PENNSYLVANIA STATE LIBRARY
General Library Bureau
Government Publications

Digitized by the Internet Archive
in 2016 with funding from
This project is made possible by a grant from the Institute of Museum and Library Services as administered by the Pennsylvania Department of Education through the Office of Commonwealth Libraries

https://archive.org/details/pleistoceneterra00pelt

PENNSYLVANIA
GEOLOGICAL SURVEY
FOURTH SERIES
BULLETIN G 23

PLEISTOCENE TERRACES
OF THE
SUSQUEHANNA RIVER
PENNSYLVANIA

BY
LOUIS C. PELTIER

DEPARTMENT OF INTERNAL AFFAIRS
WILLIAM S. LIVENGOOD, JR., *Secretary*
TOPOGRAPHIC AND GEOLOGIC SURVEY
S. H. CATHCART, *Director*
HARRISBURG, PA.
1949

03-53-887-3
VOID

COPYRIGHTED 1949
BY THE
COMMONWEALTH OF PENNSYLVANIA

Additional copies
of this publication may be purchased from
Bureau of Publications
Department of Property and Supplies
Harrisburg, Pa.

CONTENTS

PAGE

- PLEISTOCENE RIVER TERRACES OF THE SUSQUEHANNA RIVER 1
  - Introduction 1
    - General Statement 1
    - Acknowledgments 3
    - Source of the Terrace Deposits 3
      - Products of the Glacial Ice 3
      - Products of Periglacial Frost Action 5
    - Floods and Deposition 8
      - Modern Floods 8
      - Pleistocene Floods 9
    - Terraces 10
      - Methods of Collecting Data 10
      - Pleistocene Terraces 13
    - Climate 14
  - Glacial Geology 15
    - General Statement 15
    - Wisconsin Glacial Stage 17
      - General Features 17
      - Deposits of the Binghamton Sub-Stage 19
      - Deposits of the Olean Sub-Stage 20
    - Deposits of the Illinoian Stage 26
    - Presumed Glacial Deposits of Pre-Illinoian Age 30
  - Weathering 30
    - General Statement 30
    - Weathering of Pebbles 32
      - Granitic Pebbles 32
      - Quartzite 33
      - Conglomerate 33
      - Sandstone 33
      - Siltstone 34
      - Calcareous Siltstone 34
      - Shale 34
      - Chert 35
      - Summary 35
    - Soils 35
      - General Statement 35
      - Soils in the Glaciated Region 38
      - Soils in the Periglacial Region 45
      - Summary 46
  - Periglacial Deposits 48
    - General Statement 48
    - Eolian Deposits 49
      - Sand 49
      - Loess 51
    - Rubble 56
      - Congeliturbate in Areas that were Glaciated 56
      - Congeliturbate in Unglaciated Regions 59
      - Shale-Fragment Slopes 64

L318199

PAGE
Surface Features 67
    Mountain Tops 67
    Boulder-Strewn Slopes 69
    Blockfields 73

Terraces of the North Branch, Susquehanna River 75

Description of Valley 75

Terraces 77
    General Statement 77
    Composition 78
    Mankato Terraces 79
    Valley Heads Terraces 81
    Binghamton Terraces 81
    Olean Terraces 83
    Illinoian Terraces 84

Selected Localities 86
    Athens 86
    Quicks Bend 89
    Berwick 91

Terraces of the West Branch, Susquehanna River 97

Description of Valley 97

Terraces 99
    General Statement 99
    Mankato Terraces 100
    Valley Heads Terraces 100
    Binghamton Terraces 101
    Olean Terraces 101
    Illinoian Terraces 101

Selected Localities 103
    Muncy 103
    Lewisburg 107

Terraces of the Main Susquehanna River 108

Description of Valley 108

Terraces 109
    General Statement 109
    Mankato Terraces 109
    Valley Heads Terraces 110
    Binghamton Terraces 110
    Olean Terraces 110
    Illinoian Terraces 111
    Pre-Illinoian Terraces 111
    Rock Benches 112

Selected Localities 113
    Selinsgrove 113
    Harrisburg 115

Terraces of the Juniata River 120
Description of Valley 120

Terraces 122
    General Statement 122
    Mankato Terraces 123
    Valley Heads Terraces 124
    Binghamton Terraces 124
    Olean Terraces 124
    Late Illinoian Terraces 125
    Early Illinoian Terraces 126
    Pre-Illinoian Terraces 126
    Rock Benches 126

CONTENTS—*Continued*

PAGE
Selected Locality 127
Mifflintown 127

Pleistocene Climate of Central Pennsylvania 131

General Statement 131

Climate of a Glacial Maximum 134
Pressure Fields 134
Properties of the Air 135
Winds 136
Winter Weather 136
Summer Weather 137
Climate 137

Climate of an Interglacial Interval 138

Climate during Glacial Recession 138

Summary 139

Summary and Conclusions 139

Glossary 141

REFERENCES 142

INDEX 149
Geographic Index 149
Subject Index 152

ILLUSTRATIONS

FIGURES

PAGE

FIGURE 1 Map of Susquehanna Valley showing principal localities mentioned in the text and river mileages from Havre de Grace, Md. ....(Facing) 1

2 Generalized diagram showing relationship of rubble deposits to hill slopes and river terraces 5

3 Profile of the crest of the flood of March 17-20, 1936 on the Susquehanna River and its principal tributaries 8

4 Cross-section of the West Branch of the Susquehanna River at Larry's Creek showing the method of correcting the height of terraces to a common level 12

5 Map of glacial boundaries of Kansan and Illinoian stages and of four Wisconsin sub-stages in Pennsylvania and the adjacent region 16

6 Microphotographs of thin-sections of banded quartzite and granite gneiss pebbles 24

7 Geologic cross-section of hill near Selinsgrove 29

8 Geologic cross-section of Penny Hill near Montgomery 29

9 Diagrams of weathered pebbles from Illinoian glacial gravel deposits 31

10 Graphic comparison of depth of soil development and chemical change in Illinoian and Wisconsin glacial deposits 37

11 Relationship of materials exposed in gravel pit near Falls 40

12 Topographic map of the valley of the West Branch, Susquehanna River near Lewisburg showing position of terraces and of eolian deposits 50

13 Map of periglacial deposits in and near the Susquehanna Valley of Pennsylvania 51

14 Relationship of materials exposed in gravel pit at foot of Spanish Hill near Waverly, N. Y. 52

15 Relationship of materials exposed in gravel pit near Wysox 53

16 Relationship of materials exposed in road cut near Shickshinny. 54

17 Relationship of rubble to Olean till and gravel at railway station, Vosburg 58

18 Idealized geologic cross-section of hillslope near east bank of Chatham Run at Charlton 61

19 Topographic sketch of road cut in Jacks Mountain near Mapleton Depot 62

20 Geologic cross-section of east bank of road cut in Jacks Mountain near Mapleton Depot 63

21 Vertical section in a shale-fragment slope near Danville showing orientation of fragments 65

22 Sketch of the relationship between rubble and bed rock in road cut on the crest of Little Mountain 68

23 Sketch of the relationship between rubble and bed rock in road cut on the crest of Big Mountain 68

PAGE

FIGURE 24 Profile of wind gap on Bald Eagle Moutain near Montoursville showing the relationship between the rubble slopes and the blockfield in the floor of the gap 70
25 Diagram of boulder terrace on Bald Eagle Mountain 71
26 Geologic cross-section of south flank of Bald Eagle Mountain near Montgomery showing relationship of rubble and silt to underlying bed rock 72
27 Profile of grades of the several terrace systems on the North Branch, Susquehanna River 75
28 Geologic cross-section of right bank of North Branch, Susquehanna River at Greenes Landing showing terraces 78
29 Geologic cross-section of valley of North Branch, Susquehanna River at Wysox showing terraces 80
30 Map of Susquehanna and Chemung Rivers near their confluence at Athens showing distribution of terraces 85
31 Profile of terraces and projected grade lines near Athens 87
32 Profile of grade lines of terraces along Buck Creek 88
33 Profile of terraces and projected grade lines near Berwick 91
34 Geologic cross-section of road cut near Hicks Ferry 93
35 Profile of grades of the several terrace systems on the West Branch, Susquehanna River 98
36 Map of West Branch, Susquehanna River near Muncy showing distribution of terraces 102
37 Geologic cross-section of West Branch, Susquehanna River at Muncy showing terraces 106
38 Geologic cross-section of West Branch, Susquehanna River at Lewisburg showing terraces 106
39 Profile of grades of the several terrace systems on the Susquehanna River between Northumberland and Marietta 108
40 Geologic cross-section of Susquehanna River near Selinsgrove showing terraces 113
41 Diagram of right bank of Penns Creek near Selinsgrove showing relationship between Illinoian deposit and bed rock 115
42 Geologic cross-section of Susquehanna River at Harrisburg showing terraces 116
43 Profile of grades of the several terrace systems on the Juniata River 120
44 Geologic cross-section of rock bench on U. S. Highway 22 near Mount Union 125
45 Geologic cross-section of rock bench on U. S. Highway 22 near Mount Union 125
46 Map of Juniata River near Mifflintown showing distribution of terraces 128
47 Profile of grade lines of the several terrace systems on Cedar Spring Run 130
48 Hypothetical map, according to the Köppen system, of climatic zones in eastern United States during the Tazewell glacial maximum 133
49 Map, according to the Köppen system, of climatic zones in eastern United States at the present time 134

TABLES

PAGE

TABLE 1 Probable Correlation of Pleistocene Deposits in the Susquehanna Valley 4
2 Geologic Section on bank of South Branch, Cattaraugus Creek near Otto, N. Y. 16
3 Pebble Counts of Pleistocene Deposits in the Susquehanna Valley 18
4 Geologic Section on right bank of Murray Creek at Greenes Landing 19
5 Geologic Section on right bank of Mehoopany Creek near North Mehoopany 21
6 Igneous and Metamorphic Pebbles in Glacial Deposits in the Susquehanna Valley 20
7 Calculated and Observed Composition of Olean Till along a 76-mile glacial flow-line 22
8 Geologic Section in road cut and gravel pit at Luzerne 22
9 Geologic Section in road cut near Forkston 23
10 Composite Geologic Section in road cuts near Charlton 27
11 Geologic Section in pit near Dewart 29
12 Terrace Soils in the Susquehanna Valley 36
13 Geologic Section in gravel pit near Hornbrook 39
14 Geologic Section in gravel pit near Forty Fort 39
15 Geologic Section in gravel pit near Falls 40
16 Geologic Section on right bank of Tunkhannock Greek at East Lemon 41
17 Geologic Section on the left bank of Sugar Creek near Luthers Mills 42
18 Geologic Section in gravel pit near New Columbia 43
19 Geologic Section in road cut near Selinsgrove 44
20 Geologic Section in abandoned gravel pit near Marietta 45
21 Geologic Section in gravel pit near Thompsontown 46
22 Geologic Section in road cut on the north flank of Berry Mountain near Millersburg 49
23 Geologic Section in gravel pit in the north side of Spanish Hill near Waverly, N. Y. 53
24 Geologic Section in gravel pit at East Towanda (near Wysox) 54
25 Composite Geologic Section in road cut and gully near Dunnstown 55
26 Geologic Section in road cut near North Towanda 57
27 Geologic Section in road cut near Forkston 58
28 Geologic Section in excavation at Herndon 60
29 Geologic Section in road cut in Jacks Mountain near Mapleton Depot 61
30 Geologic Section in "gravel" pit near Losh Run 64
31 Geologic Section in pit near Danville 66

TABLES—*Continued*

PAGE

TABLE 32 Geologic Section in pit near Ramsay School, White Deer Township 67
33 Geologic Section in road cut on south flank of Bald Eagle Mountain 72
34 Relative Resistance of Pebbles to Stream Abrasion 79
35 Terraces of the North Branch, Susquehanna River 80
36 Geologic Section in road cut near Hicks Ferry 92
37 Geologic Section in the pit of the Hunlock Creek Sand and Gravel Co., near Hunlock Creek 94
38 Geologic Section in sand pit near Shickshinny 94
39 Geologic Section in gravel pit near Berwick 95
40 Composite Geologic Section in road cut and sand pit near Dewart 104
41 Terraces of the West Branch, Susquehanna River 104
42 Geologic Section in cellar hole on right bank of Turkey Run 104
43 Geologic Section in gravel pit near Selinsgrove 114
44 Terraces of the Susquehanna River 116
45 Geologic Section in gravel pit near Highspire 117
46 Terraces of the Juniata River 122

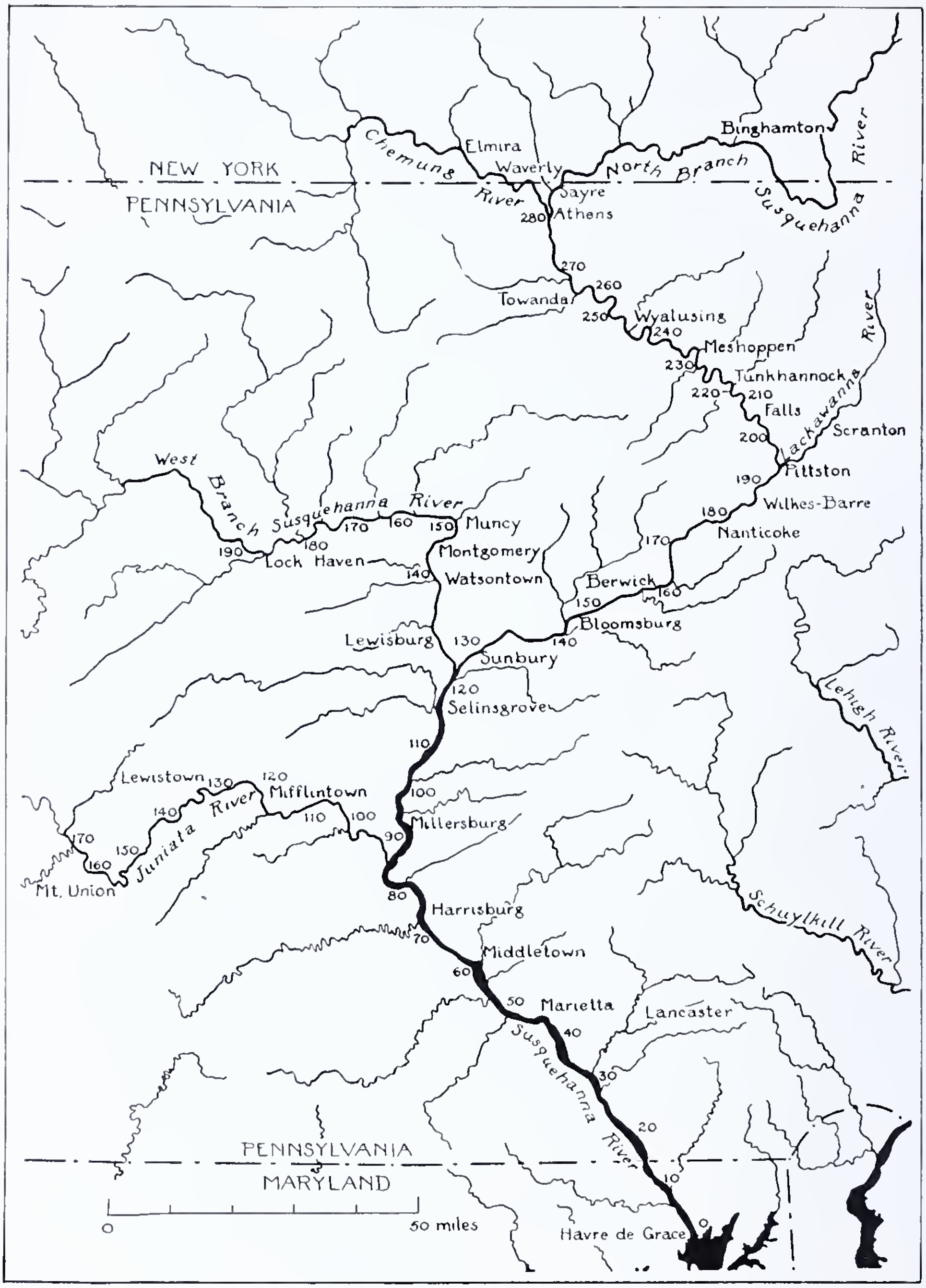

Figure 1. Map of Susquehanna Valley showing principal localities mentioned in text and river mileages from Havre de Grace, Maryland.

PLEISTOCENE TERRACES OF THE SUSQUEHANNA RIVER, PENNSYLVANIA†

BY

LOUIS C. PELTIER

Introduction

GENERAL STATEMENT

The Susquehanna River follows an irregular course across Pennsylvania to its mouth at Chesapeake Bay. Its principal tributary, the North Branch, is essentially the principal stream and rises in the western foothills of the Catskill Mountains in eastern New York (fig. 1, p. x). It is joined by two major tributaries, the West Branch of the Susquehanna, and the Juniata River, both of which rise in the Appalachian Plateau of western Pennsylvania. The several branches and the main river cross nearly all of the major physiographic provinces in Pennsylvania and their combined length is sufficient to make them a representative sample of the rivers of the northern Appalachian Mountains.

The Susquehanna and its branches are bordered by deposits of sand and gravel which form terraces[1] above the river bed. The terraces are remnants of once continuous gravel and sand plains laid down by the rivers on a continuous grade, now represented by the height of the existing remnants. The sands and gravels of the terraces are coarser than the sands and silts now carried by the rivers. These successive stages of alluviation were, therefore, not laid down by floods similar to those of the present, but are to be correlated with the glacial climatic regimes of the Pleistocene. Thus, the terraces are indices of Pleistocene chronology. The history of the development and erosion of the soil and also some of the broader aspects of the geomorphic history of the northern Appalachian Mountains may be related to this chronology. Ashley (1933) has already indicated the possible application of terrace studies along the Susquehanna River to the problems of Early Man. Stone implements, including "Folsom-like" points, have been found in scattered places in the Susquehanna Valley (Howard, 1934, 1942; Shaeffer, 1941; Stewart, 1938). None of these points, so far as is known, have been found in the river gravels. This may be because the Mankato terrace, with which artifacts of Folsom type should be associated (Bryan, 1941), is nearly everywhere buried beneath a deposit of modern silt.

---

† Submitted to the Division of Geological Sciences, Harvard University, as partial fulfilment of the requirements for the degree of Doctor of Philosophy, May 1, 1948. Received for publication by the Pennsylvania Topographic and Geologic Survey, July, 1948.

[1] In this discussion a terrace is defined as a topographic feature consisting of a steep face and a flat top. It consists of alluvial deposits, which may or may not rest upon rock surfaces, here referred to as rock benches. The terrace height is the vertical distance from the mean low water level of the river to the break in the relatively steep riverward slope of the terrace. The terraces of subequal height are remnants of once continuous alluvial plains and valley trains.

Those terrace gravels, which are direct outwash from the glacial ice, are an economic resource whose commercial value varies according to their location and to their antiquity. The gravels of the relatively recent Binghamton and Valley Heads glacial sub-stages are less weathered and contain a larger proportion of inherently strong pebbles such as quartzite, granite, limestone and chert, than do those of the older stages. The Olean gravels have deeper weathering and a relatively high proportion of more readily abraded, platy siltstones and fine-grained sandstones. They are, therefore, of inferior quality for some construction purposes. The Illinoian gravels are quite thoroughly weathered and most of the pebbles are weak and even crumbly, hence the use of Illinoian gravel is distinctly limited. The gravel deposits of the periglacial terraces, such as those along the Juniata River, are generally too thin and dirty to be of high commercial grade.

The quality of the water in the North Branch of the Susquehanna River is related to the composition of the Pleistocene deposits. The Binghamton and Valley Heads gravels have a distinctly higher limestone content than do those of Olean age. This feature is shown along the Tioga-Chemung-Susquehanna River system (fig. 1, p. x). The Tioga River, which flows northward toward the Binghamton glacial boundary, contains some waste from coal mines and is acid. As these waters flow into and are mixed with the waters of the Chemung River, they are neutralized. The river water has a low acidity along the lower part of the Chemung River and along the North Branch of the Susquehanna River, which it joins. It retains this property until it is mixed with water from the Lackawanna River and the Wyoming Basin, which is contaminated by the waste of the coal mines and the cities.

This paper is directed toward the establishment of a Pleistocene chronology for central Pennsylvania and the determination of the climatic fluctuations which occurred during that period. Terraces were studied on the main Susquehanna River above Marietta (m.44)[1], on the North Branch below Waverly, New York (m.286), on the West Branch below Lock Haven (m.189), on the Juniata River below the junction of the Raystown and Frankstown Branches (m.169), and on several smaller tributaries, a total distance of 440 miles. Within a distance of 35 miles below Marietta the river falls 228 feet through a narrow gorge in which few terrace remnants are preserved. The behavior of the terraces under these conditions, and their correlation with the marine terraces of the coastal plain, constitute a separate problem beyond the scope of this paper.

The Susquehanna River flows across an area which has become classic in the study of Appalachian physiography. It has been described by W. M. Davis (1889, 1896), Barrell (1920), M. R. Campbell (1903, 1929, 1933), E. B. Knopf (1924), Bascom (1924), Fridley (1929), Ver Steeg (1930), D. W. Johnson (1931), Ashley (1930, 1933, 1935), Strahler (1945), Bryan, Cleaves and Smith (1933), Mackin (1933, 1934, 1936), Hickok IV (1933), Itter (1938), Cole (1941) and others. These writers have been primarily concerned with erosion surfaces and the erosional history of the area. As is shown on page 114, all of these erosion surfaces, of Somerville age or older, are older than Illinoian in age.

---

[1] Places near the river are located in terms of miles along the centerline of the river above the Pennsylvania Railroad Bridge at Havre de Grace, Maryland. The mile stations are here abbreviated as m. followed by a numeral.

ACKNOWLEDGMENTS

The field work in 1942 was carried out with the assistance of a grant from the Sayles Fund, administered by the Division of Geology in Harvard University. The field work of 1946 was conducted under the provisions of Public Law 346 ("G. I. bill").

The writer acknowledges with gratitude the interest and generous assistance of many individuals. Professor Paul MacClintock joined the writer in the Susquehanna River field area in 1941 and gave sincerely appreciated encouragement and advice. In addition he made helpful suggestions after a critical analysis of the manuscript. Professor Kirk Bryan spent several days in the field with the writer in 1941 and in 1946, and has been an inspiration in devising methods of field work and laboratory analysis. He has also rendered assistance pertaining to the manner of presentation of the material obtained, and has constructively criticized the manuscript. Dr. E. A. Norton was of great help in compiling bibliographical material concerning the soils of Pennsylvania. He loaned the writer many reports from the files of the United States Department of Agriculture. Dr. Victor Conrad graciously read and criticized that part of the manuscript dealing with paleoclimatology. Dr. Erwin Raisz gave sincerely appreciated advice in the preparation of the maps and illustrations that accompany the text. The Pennsylvania Topographic and Geologic Survey, at that time under the directorships of Dr. George H. Ashley and Dr. Ralph W. Stone, was of great assistance. Its files, which include unpublished maps, longitudinal profiles, and notes of W. O. Hickok IV, Forrest T. Moyer, and M. R. Campbell, were opened to the writer and were consulted freely. Professor Arthur B. Cleaves assisted in editing the manuscript. Louisa R. Peltier assisted in editing and proof reading the manuscript.

In acknowledging assistance the writer assumes full responsibility for errors in fact or analysis.

SOURCE OF THE TERRACE DEPOSITS

Products of the Glacial Ice.

Glacial ice entered the upper part of the Susquehanna Valley at least once during the Illinoian stage and at three different times during the Wisconsin stage. These ice advances occurred during the Illinoian stage and the Olean, Binghamton and Valley Heads sub-stages of the Wisconsin (Table 1, p. 4). The rare occurrence of granite pebbles on terraces above the Illinoian outwash appears to indicate that one or more advances of glacial ice into the Susquehanna Valley occurred in pre-Illinoian time. The available evidence as to the nature and continuity of these deposits is too meager to be conclusive.

TABLE 1. *Probable Correlation of Pleistocene Deposits in the Susquehanna Valley*

UPPER MISSISSIPPI VALLEY	WESTERN NEW YORK	SUSQUEHANNA VALLEY		
till and outwash	till and outwash	till	outwash	periglacial gravel
Mankato	*Mankato*	absent	absent	*Mankato*
weathering	weathering			
Cary	*Valley Heads*	absent	*Valley Heads*	*Valley Heads*
slight weathering and erosion				
Tazewell	*Binghamton*	*Binghamton*	*Binghamton*	*Binghamton*
weathering and erosion				
Iowan	*Olean*	*Olean*	*Olean*	*Olean*
strong weathering and erosion				
Illinoian	*Illinoian*	*Illinoian*	*Illinoian*	*Late Illinoian* *Early Illinoian*
weathering				
Kansan	absent	absent	scattered bodies of gravel	scattered bodies of gravel
Nebraskan				

The glacial stages and sub-stages of the Susquehanna Valley are correlated with those of western New York, described by MacClintock and Apfel (1944). The Hamburg and Marilla moraines are considered to be the equivalent of the Port Huron and, therefore, to be Mankato in age; and the Valley Heads moraine to be Cary in age. According to them the Binghamton deposits are either Cary or Tazewell in age, and those of the Olean ice belong to either the Tazewell or Iowan sub-stage. There is sufficient difference in weathering and soil development between the Valley Heads, Binghamton and Olean deposits in Pennsylvania, both in the area covered by MacClintock and Apfel and in the Susquehanna Valley, to indicate that they were separated from each other by significant intervals of time. Each is also represented by a separate and distinct outwash terrace or pair of terraces. On these grounds the Olean is considered to be distinctly older and, therefore, Iowan in age. The Binghamton and Valley Heads are, with less certainty, considered to be Tazewell and Cary in age respectively (Table 1, p. 4). This is in agreement with the correlation suggested by Flint (1947).

The glacial deposits, here called Illinoian, are characterized by thorough leaching and weathering to a red or reddish-brown color. They are assigned to the Illinoian stage because of this distinctive appearance and because the outwash of this stage has formed terraces which lie immediately above the Olean terraces with no evidence of an intervening stage of alluviation.

During each glacial stage large quantities of debris of all sizes were carried by the streams which flowed from the ice edge. The existing terraces are graded not to the most advanced position of each ice sheet, but to positions of the retreat. Debris was deposited during each ice advance, but it cannot be distinguished from that carried by the meltwaters of the retreating ice. The debris of the advance must have been either relatively small in volume, redeposited, or else buried by the outwash laid down during the glacial recession. A sufficient quantity of outwash was carried downstream to choke the valley for 150 to 200 miles from the ice front. The gravel flood reached a depth of 80 feet during the Illinoian stage, and was deposited at successively lower levels during each succeeding sub-stage. The problem posed by the more or less regular diminution in height of outwash with each younger glacial stage is discussed on pages 110-111. Following each glacial stage or sub-stage the regime of the streams so changed that the alluvial fill along the channel was washed out to bedrock and presumably carried to the sea.

Products of Periglacial Frost Action.

The slopes of all of the hills and mountains in the Susquehanna Basin are mantled with a layer of rubble from 4 to 70 feet thick. Such a mantle is illustrated in Figure 2, (p. 5). This rubble, described in detailed on pages 56 to 74, is derived from the slope on which it is found and is composed either of reworked till or of fragments broken from the country rock. In all instances it has moved down the slopes, either slowly or spasmodically. Projecting blocks or rubble and scattered rock outcrops make each slope intimately rough and difficult to traverse. When broadly considered, however, the slopes of the hills are smooth, falling into gently curving contours. The gradient varies from steep near the top to gentle at the base, or between 25 and 2 degrees. Rock outcrops are numerous in the steep areas at the top

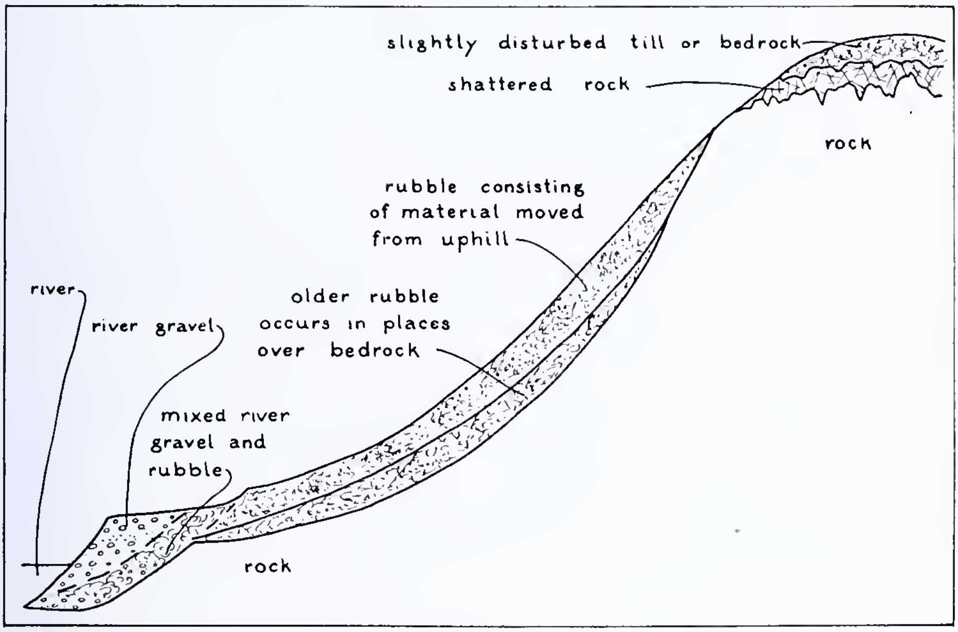
slightly disturbed till or bedrock
shattered rock
rock
rubble consisting of material moved from uphill
river
river gravel
older rubble occurs in places over bedrock
mixed river gravel and rubble
rock

FIGURE 2. Generalized diagram showing relationship of rubble deposits to hill slopes and river terraces.

of the slopes, and rare below. The rubble is irregular in thickness. The sum of the irregular bedrock surface and unequal cover of rubble is the sweeping slope unadjusted to modern erosion. There is no evidence that this rubble is now moving. The slopes are stable and are now, or were once, covered with forest. The boulders strewn over the slopes are weathered and immobile, for there are no furrows in the ground on their upslope side, nor is the ground plowed-up on their downslope side. They are not piled up against the trees. A soil profile has developed and on many slopes the soil development equals that found in areas of like surface gradient which are underlain by Olean till. In places the rubble-covered slopes are dissected by gullies up to 10 feet in depth. These gullies cut through the rubble. There is no indication that a fresh addition of rubble has hindered the downcutting of the gullies. The gullies contain silt instead of rubble. The rubble slopes must, therefore, have been formed by a process which was active in the past, but which is no longer effective.

In some places, where the rubble is composed chiefly of an easily weathered shale, the soil is thin and many of the shale fragments are strong and only slightly weathered. It is difficult to imagine a slow, downhill movement of these fragments from their parent outcrop to their present position, under modern climatic conditions, without their succumbing to weathering. They must have reached their present position at a time when chemical weathering was a much slower process than at present. Rubbles of unweathered fragments form today under Arctic climates, as shown by Högbom (1913).[1] Similar smooth, rubble-covered slopes were described by Denny (1938) from the Hudson River Highlands only 100 miles to the east. He followed European precedent and attributed the rubble layer to an intensely cold, periglacial climate. Obviously the rubbles of Pennsylvania may also be attributed to periglacial climate contemporaneous with one or another of the glacial sub-stages, represented elsewhere in the Susquehanna Valley by a till sheet or by a terrace.

The characteristics of the periglacial climate must be inferred from the phenomena found. The depth of freezing, and the frequency of soil temperature fluctuations about the freezing point, were presumably much greater than occur in the valley today. Thus bedrock was severely shattered and large quantities of fresh, angular rubble of all sizes were produced. During warm seasons the upper part of the frozen ground thawed and formed a plastic, saturated layer which moved downslope, as is shown in Figure 2 (p. 5). During stream flood stages the rubble mass in the valley bottoms was strongly eroded. The pebbles and smaller particles were swept away and incorporated in the bed-load of the stream; cobbles and boulders remained in place and became surrounded by river gravel. Contributions of rubble to the bed-load of the streams make up nearly all of the alluvium now found on the periglacial terraces of non-glaciated valleys. This relation is considered more fully on page 59.

In addition to the ubiquitous rubbles, the area is characterized by widely distributed, but thin, deposits of silt and fine sand. These deposits lie upon till or rubble slopes and upon the gravels of all of the outwash terraces. There is little stratigraphic evidence to prove their age, but they show distinct differences in weathering and cannot all be contemporaneous. Some show the characteristic rubification of Illinoian till and outwash; others are oxidized to a buff or tan color, as are the Wisconsin glacial deposits. In a few places (pp. 40 and 41) a younger silt has been deposited upon an older one. At one place a deposit of unoxidized silt and very fine sand, described on page 55, was found on a mountainside above the river. The unsystematic location of these deposits and their lack of sorting are proof that they are not water-laid. They appear, instead, to be wind-laid or wind-borne. Some of the fine sand occurs in low dunes adjacent to old positions of the river, as shown on page 49. The silt, however, has been carried by the wind to places far removed from the river and exists in nearly every location where it has been protected from erosion.

---

[1] For more recent work, and extensive bibliography, see Steche (1933).

The present climate, as well as the more or less similar climate that prevailed between the glacial stages, is not favorable to the formation of these wind-borne or wind-laid deposits. They must have been laid down at a time when the outwash plains of the river were barren of vegetation and when the climate was such that unweathered silt could be obtained and could also be moved without becoming immediately oxidized. They are, therefore, glacial rather than interglacial or interstadial in age. It is supposed that they are composed of rock flour from glacial outwash streams and from the till surface, and of the fine products of *congelifraction*[1] in the periglacial region (Dücker, 1937; Zeuner, 1945). The erosion, transportation and deposition of these wind-borne deposits could not have occurred in a climate like that of today, for now all of the countryside, except where disturbed by man, is covered with vegetation which reduces the wind velocity at the surface to a negligible amount. Presumably the interglacial and interstadial intervals were equally unfavorable.

The ages of the deposits of wind-borne silt are determined by the degree of soil development which they have undergone. This procedure is supported by stratigraphic evidence, for the silts are commonly found lying upon the unweathered surface of a glacial deposit. As no time interval, sufficient to weather the till or gravel and produce a soil, elapsed between the deposition of the glacial deposit and that of the silt, the silt must have been deposited during the same glacial substage as was the till or gravel. At other places the silt occurs associated with rubble deposits. Here the silt was penecontemporaneously deposited with the underlying rubble, with which it may be found mixed. However, in places, the rubble is separated from the overlying silt by a slightly developed soil.

Wind-borne silt might have been deposited during the early part of a glacial sub-stage, but if so it was more or less simultaneously removed by *congeliturbation*.[2] On the evidence available in the area, the deposits which remain are features of the ice recession.

---

[1] The word *congelifraction* was introduced by Bryan (1946) for the process of splitting apart by frost.

[2] *Congeliturbation* is the process whereby ground is disturbed by frost. This word was introduced and defined by Bryan (1946).

FLOODS AND DEPOSITION

Modern Floods.

Reconstructed longitudinal profiles of the roughly parallel Pleistocene outwash terraces show an essential parallelism to the modern flood grade. This parallelism indicates that the terrace gravels were laid down by floods which were, in some respects, similar to modern floods. The best known modern flood is that of March 17-20, 1936, described in Water Supply Paper 799 of the United States Geological Survey (1937). The profile of its crest, shown in Figure 3 (p. 8), varied in height directly as the discharge and inversely as the velocity of flow.

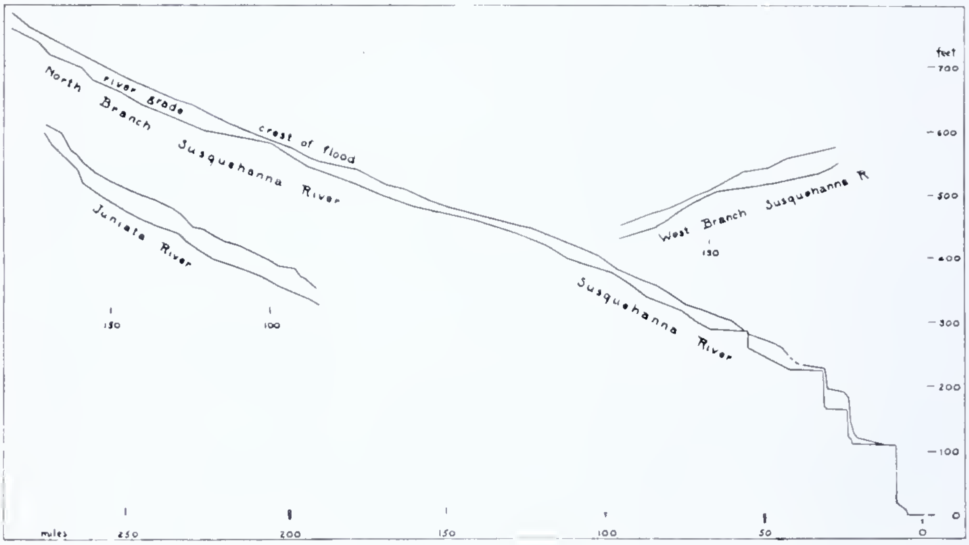

FIGURE 3. Profile of the crest of the flood of March 17-20, 1936 on the Susquehanna River and its principal tributaries.

The effect of changes in the area of cross-section of the channel was relatively small, and the effect of bends or obstacles in the channel was negligible. The height of the crest above the low-water grade ranged from 6 to 30 feet. It was lowest near the headwaters, where the discharge was low, and increased in height downstream. This increase is normally expected as the result of the increment of the tributaries and the downstream decrease in the channel gradient. There are several places, shown in Figure 3 (p. 8), where there was a local lowering of the flood crest. There was also a lowering of the flood crest toward the mouth of the river. These decreases in crest height were due to: (1) local increases in the channel gradient and the development of a drawdown curve, or (2) channel losses to the groundwater which exceeded the increment of discharge from local tributaries.

The alluvial surfaces here considered were built by glacial floods which, except for an abrupt beginning at the ice front, were like the modern floods in that contributions from tributaries continued to be made. The alluvium carried was, however, mainly derived from the ice front. Near the ice front the longitudinal profile of an ideal alluvial plain of this type and of great length should be much steeper than the low-water grade line of the stream. Downstream, however, as channel losses become significant, it should become gentler and the two profiles should converge toward the mouth. Local fluctuations superimposed upon this general gradient should occur. Thus, wherever the channel gradient becomes steeper, the alluvial plain should approach the bedrock floor of the valley; wherever the channel gradient is flattened, the alluvial plain should rise. These local variations in grade occur in the grade line of modern floods like that of 1936 and in modern flood deposits. The local variations in grade also occur in the grade lines of the Pleistocene terraces at the same localities as shown in Figures 27, 35, 39 and 43 (pp. 75, 98, 108, 120). Presumably these variations in grade exist for reasons similar to those which cause the fluctuation on the grade lines of modern floods (fig. 3, p. 8).

Pleistocene Floods.

Whereas the Pleistocene floods which laid down the terrace gravels had gradients similar to those of modern floods, in other respects they were different. The bed-load transported by glacial floods was greater in amount and larger in grain size than that carried by modern floods. The modern Susquehanna River carries a small load of silt and sand, which at no time reaches the maximum capacity of the stream. The contribution of new debris, by erosion of the valley walls along the course of the river, is relatively slight. As a result there is a general tendency for the river and all of its tributaries to scour their beds during flood stages. The modern floods are induced by heavy rains which, on occasion, are augmented by water from melting snow. Over a large part of the river course the volume of the flood increases by additions of the floods of the tributary creeks and the total discharge increases downstream, but there is no corresponding increase in load. Most of the material carried and temporarily deposited is silt or silty sand, and there is little or no gravel.

During the glacial stages, however, the regime of the river and of the tributary streams must have been different, for the materials deposited are coarser in grain size and also better sorted. The sand or gravel is generally clean and free from silt. These characteristics, coarseness and a high degree of sorting, are well-known features of glacial outwash. They are obviously the result of the regimen of glacial rivers which commonly have diurnal floods of short duration during the summer. These floods were occasionally augmented by the run-off of heavy rains which fell over the glacier. Furthermore, in the winter the rivers were presumably dry, as winter melting of the ice was presumably a rare phenomenon. Diurnal floods and summer concentration of run-off on Swiss rivers fed by glaciers and snow fields have been described by Collet (1925). As the size of the particles carried by these floods was much greater than is now carried, the regime of the stream must have been different, due either to lack of hindrance to flow, by vegetation, or to a greater flood discharge. On the Susquehanna River glacial floods differed from modern floods in that they were not significantly augmented by floods on the smaller tributaries remote from the ice front. This, coupled with the high permeability of outwash gravels, caused the ordinary daily glacial flood discharge to decrease downstream from its source in the ice front. For this reason the outwash gravels begin to lose some of their characteristic sorting and lack of fines at a distance of 100 to 200 miles from the ice edge. In terms of use of the material, it becomes dirty and less valuable as a building material. The streams received a heavy load of sand and gravel from the wasting ice mass and a large contribution from the unstable, frost-heaved, rubble-covered slopes of the valley walls. These combined sources overloaded the stream with respect to the coarse sizes and led to the alluviation of the channel. The Pleistocene terraces, here under consideration, are the remnants of several such stages of alluviation.

Along the Juniata River and other tributaries whose valleys were not invaded by glacial ice, the coarse alluvium could only have been derived from the valley walls. The quantity of the load was presumably smaller than on the outwash-bearing streams, but alluviation took place. As no large bodies of ice were present, no large volumes of meltwater and no daily floods, such as occur on proglacial streams, occurred. The floods were produced chiefly by the melting of snow and ground ice and by the rapid run-off of heavy rains from the areas where the permeability of the soil had been reduced by its permanently frozen condition. The deposits of these floods are, compared to the glacial outwash, poorly sorted and contain silt mixed with the dominant sand or gravel. Apparently the floods on the periglacial streams were more nearly like those of modern streams, but differed in the size and quantity of the bed-load. The coarseness of the bed-load was, however, sufficient to cause alluviation rather than channel-cutting.

Within the glaciated region large quantities of available debris served to retard channel-cutting and to promote, instead, the lateral migration of the stream. This principle is illustrated by the experiments of Friedkin and others (1945) in which the flow of water over a sand surface was studied. The amount of post-Illinoian down-cutting is negligible, as discussed further on page 115. Beyond the glaciated region, and on those streams where the floods were smaller, the channel may have been swept clean early in the interval between glacial advances. Were this so, cutting of the bedrock channel should have occurred. The Susquehanna has been studied only as far as Marietta (m.44), 70 miles from the Illinoian ice limits, and this predicted condition has not been found. However, downcutting of the channel may have begun near the mouth of the river during Sangamon time and its influences may not yet have extended north of Marietta.

TERRACES

Methods of Collecting Data.

The identification and correlation of the terraces were made on the basis of three lines of evidence: the relative elevation of the terraces, the weathering of the terraced deposits, and the lithologic composition of the gravels in the terraces. Wherever continuous, the terrace surfaces were traced directly downstream and restored grade lines were related to nearby surfaces of similar elevation above the river; where discontinuous, the terraces were independently identified on the basis of their relative height above the mean low-water stage of the river, and the weathering and composition of their gravels. Deposits of similar weathering were assumed to be of similar age and to belong to the same reconstructed outwash plain, as discussed on page 30. Outwash deposits were correlated with the till of the same age by comparison of pebble counts, as shown on page 81 and in Table 3 (p. 18).

The terraces were traced downstream and mapped on topographic maps of the U. S. Geological Survey or the tactical maps of the U. S. Army, Corps of Engineers, scale 1:62,500, as shown in reduced scale in Figures 30, 36 and 46. A total of 61 cross-section profiles were constructed by pace and hand level on a scale of 1:2400, with a vertical exaggeration of 4 and probably subject to a 10 per cent error. Profiles were made across every major terrace remnant on the North Branch of the Susquehanna River and the Juniata River, and at widely spaced intervals on the West Branch and the main Susquehanna River. Unpublished plane table maps of the Susquehanna River and its West Branch, on scales of 1:1000 and 1:1800 with 5-foot contour intervals, surveyed by W. O. Hickok IV and F. T. Moyer under the direction of the Pennsylvania Topographic and Geologic Survey, were available and were extensively used.

The gradients containing the terrace remnants whose age is presumed to be the same and which represent the gradients of outwash plains, were correlated graphically by the use of a longitudinal profile of the river, on a scale of 2 miles to the inch or 1:126,720. The positions of terrace remnants were projected on this profile and grade lines were then constructed, as shown for small sections and on reduced scale in Figures 31 (p. 87) and 33 (p. 91). The terrace remnants as mapped in the field, as shown on cross-sections made by pace and compass, and as indicated by the contour maps of Hickok and Moyer, were projected on the main profile. The correlations of terrace remnants were checked against observations on 78 measured sections of outwash deposits made in road cuts, in gravel pits and on river banks. In these localities the age of the deposits was determined by their composition (p. 18), soil development, oxidation, leaching and disintegration of their pebbles (p. 30). These terrace remnants, unlike those described by Flint (p. 136, 1947), slope from the valley walls toward a centerline in the original plain of deposition at a gradient of 1 to 3 degrees. Where the river, by lateral erosion, has forced back the face of the terrace remnant, its height is greater than in places where the terrace remnant is relatively uneroded and lies near the center of the original plain of deposition. The longitudinal profile of the centerline is, therefore, slightly lower than that constructed from the horizontal projection of the terrace edges to the centerline of the present river.

Figure 4 (p. 12) shows the Binghamton terraces on both banks of the West Branch, Susquehanna River, at Larrys Creek (m.174) and illustrates the error which is introduced by projecting the terrace height horizontally to the centerline of the river. The edge of the Binghamton terrace on the north bank, on the outside of the river bend, is 5 feet higher than the edge of the corresponding terrace on the opposite bank. The height of this terrace is, therefore, either 25 or

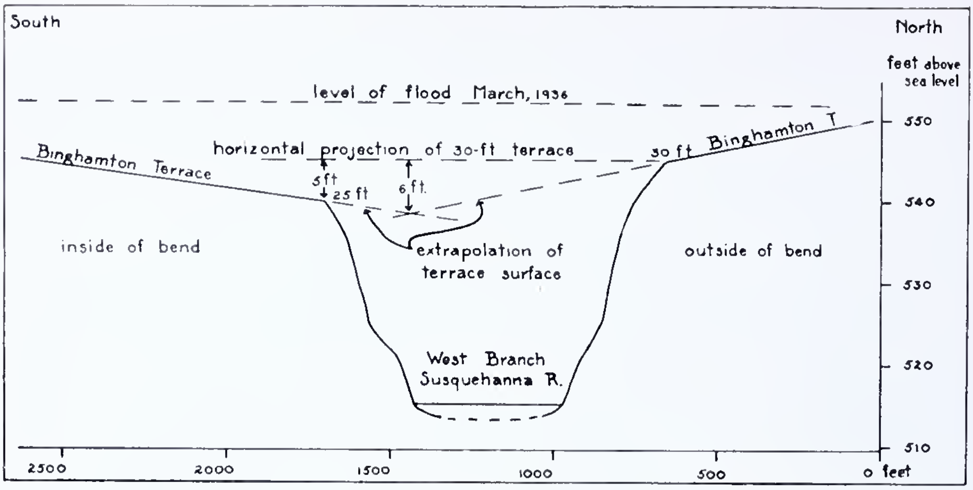

FIGURE 4. Cross-section of the West Branch of the Susquehanna River at Larry's Creek (m.174) showing the method of correcting the height of terraces to a common level.

30 feet depending upon which bank of the stream is considered. This discrepancy may be resolved if the surface of each terrace is projected toward the center of the river. These projected lines meet at a height of 24 feet. This height may be taken as an approximation of the original level of the valley fill during Binghamton time.

The lowest point on the reconstructed surface, shown in Figure 4 (p. 12), lies close to the south bank of the river. It is assumed to represent the location of the river channel during Binghamton time. Since that time the bank on the outside of the bend in the river has been eroded and the front of the terrace moved back so that it now intersects the terrace surface at a greater height than does the relatively stationary terrace front on the opposite bank.

Observations on the terrace profiles within the glaciated region indicate that further refinement on the reconstruction of the surface of the valley fill is possible. Here, the cross-section of the terraces decreases in gradient from about 3 or 4 degrees to less than 1 degree. The terrace surface is, therefore, neither a horizontal nor a gently inclined plane, but a gently curved concave-upward surface. This curved surface is assumed to have been produced in part by the accumulation of slope wash at the foot of the valley walls and in part by the erosion by the floodwaters of the streams during the transition period from valley-filling to channel-cutting. The curvature of the terrace surface may, then, reflect the relative frequency with which different parts of the terrace surface were influenced by this type of flood.

Terraces, older than Binghamton in age, rarely occur on both sides of the river at any one place. The writer has, therefore, been unable to determine the error in the elevation of these higher terraces. However, at nearly all places measured, the difference between the projected grade line and the presumed original grade line was of the order of 5 feet or less. This difference falls close to the error in determination of the altitude of the higher terraces above the river. Uncorrected values for the height of the terraces are used throughout this paper because the corrected terrace height is not as readily recovered as the uncorrected value and because the magnitude of the differences is small.

Pleistocene Terraces.

Terraces representing six Pleistocene outwash plains and scattered evidence of other older plains, also presumed to be Pleistocene, were found within the Susquehanna Basin. Of these, four are of Wisconsin age; one or two are of Illinoian age; and others are of pre-Illinoian age. Terraces of Binghamton, Olean and Illinoian age have been traced into the till-covered area of their respective glacial stages and are directly correlated to the glacial deposits. The Valley Heads and Mankato terraces are so identified because they lie below and are obviously younger than the Binghamton terrace. The pre-Illinoian terraces are poorly preserved, but enough of their gravel remains to indicate that they represent stages of alluviation. Presumably they represent one or more cold stages during the Early Pleistocene.

The alluvial terraces are of two kinds, remnants of outwash plains from glacial ice and somewhat similar alluvial plains built up under periglacial conditions. The outwash terraces are formed of thick gravel beds whose surface represents the level to which the valley was filled by sediment derived from glacial ice, and below which the river has cut a trough during interglacial or interstadial intervals. Each glacial stage produced a separate alluvial fill or outwash composed of gravel distinct in lithology. The contributions to each deposit derived from reworking the next older deposit are negligible. Thus the inference here made that each period of alluviation was separated from the previous one by a distinct period of erosion is supported not only by morphological but also by stratigraphic evidence.

Along the Juniata River, which was, so far as known, unglaciated during the Pleistocene, there are periglacial terraces composed of thin gravel beds lying upon rock benches. The surface of the rock was cut penecontemporaneously with deposition, but it is not known whether the entire bench was cut at this time or merely modified from some nearly similar previous form. These terraces correspond in elevation and merge with terraces on the Susquehanna River. The gradient of the Juniata River is so steep that the successive alluviations of the main Susquehanna River could not have produced the terraces on its tributary by change in base level and backwater effects. The Juniata terraces are similar to those described by Soergel (1924) in Thuringia and demonstrate the existence of stages of alluviation, in an unglaciated valley lying in the periglacial region, which correspond in number and magnitude to the glacial stages on the Susquehanna River. Terraces on many other streams in the Appalachian region south of the glacial boundary are presumably also periglacial in origin and may eventually be correlated with the glacial stages and sub-stages.

The terrace profiles shown in Figures 27, 35, 39 and 43 (pp. 75, 98, 108, 120) give no indication of any significant postglacial tilting of the earth's surface along the Susquehanna River. Data compiled by Flint (1947) indicate that the Susquehanna Valley, below a point near Berwick (m.158), lies beyond the limits of post-glacial warping.

Above Berwick the effects of such warping were apparently so slight that they were obscured by local fluctuations in the flood profile.

Each terrace gradient is distinct in elevation and its material is differentiated by weathering from those of greater or lesser age. Each is continuous for a long distance along the Susquehanna and Juniata Rivers and is represented by contemporary terrace grade lines on all tributary streams. Each terrace grade line and the gravels of each remnant must, therefore, represent a distinct cold period separated from other periods of cold and of alluviation by a period of mild climate and erosion.

CLIMATE

A climatic rather than a strictly stratigraphic interpretation of the terraces is required, for they are more closely related to the climatic fluctuations of the Pleistocene than to specific till sheets of the several ice advances. The nature of these climatic fluctuations is indicated locally by periglacial phenomena here described (p. 48). The existence of cold climates far south of the glacial boundary is also indicated by the plant fossils found in various localities in eastern United States, as further discussed on page 132.

During each glacial stage a cover of ice extended from the polar regions into mid-latitudes. This body of ice was large enough to become a source region for an air mass. The fact that the continental ice increased in area is proof that an air mass cold enough to support the presence of ice predominated, not only near the glacier, but over the adjacent unglaciated region as well. Under such circumstances the cold anticyclone over the ice mass dominated the adjacent region, forcing the storm-paths to the south and displacing the tundra and taiga toward the equator.

Conversely, the disappearance of an ice sheet was associated with the advance of tropical air over the ice edge and the northward shift of the tundra and taiga zones. This change produced rapid melting and heavy rainfall along the periphery of the ice and it is likely that the greatest floods occurred at this time.

The climate of the Susquehanna Valley during an interglacial period, as indicated by the post-Illinoian soils and elsewhere by plant fossils, was similar in many respects to that found in North Carolina or Virginia today. During the interstadial periods the climate was probably as cool as, or somewhat cooler than, the present.

A strictly stratigraphic interpretation of the Pleistocene is not suited to the study of continental deposits remote from either till sheet or coastal terrace. Direct stratigraphic correlation is generally impossible. The common practice of considering all events which occurred before the deposition of a till sheet as pre-glacial, and those which occurred after the exposure of a till sheet to erosion as post-glacial is misleading, for it has the effect of limiting time by space and consequently the terms have different meanings in different places. Under such definitions the terms pre-glacial and post-glacial cannot be extended beyond the glaciated region.

It is, therefore, necessary in this discussion to relate the Pleistocene deposits and events to climatic episodes, to which fluctuations in the position of the ice edge are also to be related. The deposits of rubble, wind-borne silt and terrace gravel represent seven cold stages in the region of the Susquehanna Valley, of which four are correlated with till sheets which lie in the valley. These phenomena indicate that the climatic history of the Pleistocene was more variable and more complex than is indicated by the till sheets alone. This history and its probable relationship to the other episodes of the Pleistocene in North America are shown in Table 1 (p. 4). The correlations shown in this table are discussed on page 140.

The successive terrace grade lines of the lower Susquehanna and Juniata Rivers also indicate that there were, during the Pleistocene, at least seven cold periods, each one of which was followed by a period of milder climate. Hence, at least seven climatic cycles during the Pleistocene are indicated. The relative magnitude and length of these cycles suggest that they can be assigned to three major stages: the Wisconsin, the Illinoian, and a pre-Illinoian stage. The pre-Illinoian gravels may be either Kansan, Nebraskan or both. Because no pre-Illinoian glacial deposit is definitely identified, the attribution of these gravels to Kansan or Nebraskan is premature.

Glacial Geology

GENERAL STATEMENT

The Susquehanna River Basin was invaded by glacial ice not less than three times. The southern limit of glacial till pertaining to each advance is shown in Figure 5 (p. 16). The Binghamton and Olean sub-stages of the Wisconsin were named and mapped in western New York by MacClintock and Apfel (1944). The Illinoian stage in Pennsylvania was recognized and described by Leverett (1934). The deposits of the Binghamton glacial sub-stage cover most of northwestern Pennsylvania and occur in a small area of about 75 square miles near the junction of the Chemung River and the North Branch of the Susquehanna River (m.278). Deposits of the Olean sub-stage extend over a large area east and southeast of the Salamanca re-entrant and are exposed over a smaller area beyond the Binghamton moraine in the northwestern part of Pennsylvania. Thick deposits of Illinoian till and gravel occur in three separate regions: south of the Wisconsin moraine in northwestern Pennsylvania; near the junction of the North and West Branches of the Susquehanna River (m.123); and along the Lehigh River.

The Binghamton deposits are relatively unweathered and retain, to a large degree, the topographic forms of glacial deposition. The Olean deposits are slightly more weathered and in places have retained some of their original glacial forms. The stratigraphic relationships of these sub-stages to each other and to the Illinoian stage are well shown in the bank of the South Branch of Cattaraugus Creek south of Otto, New York (Table 2, p. 16), described by MacClintock and Apfel (1944). Here Binghamton gravel and till lie upon Olean gravel which overlies a thin peat bed that, in turn, separates the Olean deposits

L318499

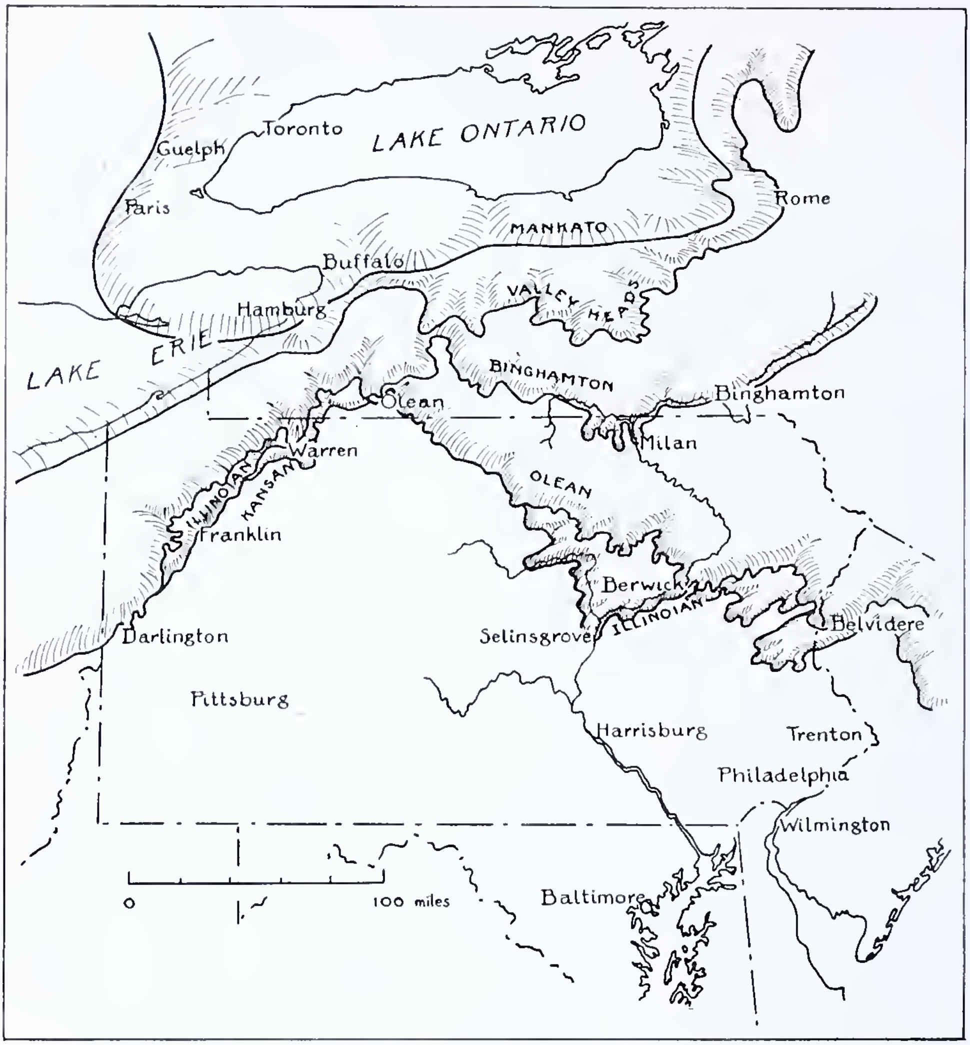

FIGURE 5. Map of glacial boundaries of Kansan and Illinoian stages and of four Wisconsin sub-stages in Pennsylvania and the adjacent region.

from a gravel presumed to be of Illinoian age. MacClintock and Apfel (1944) traced the boundary between the Olean and Binghamton deposits eastward to Milan, Pennsylvania, on the Susquehanna River (m.276) and thence eastward past Binghamton, New York. They correlated the Valley Heads moraine, in central New York, to the Cary sub-stage of the Upper Mississippi Valley. They considered that

TABLE 2. *Geologic Section on Bank of South Branch of Cattaraugus Creek near Otto, N. Y., Cattaraugus, N. Y., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Gravel, *Binghamton*, oxidized	0 to 10	
2.	Till, *Binghamton*, blue-gray, calcareous	0 to 50	
3.	Silt and clay, *Olean* (?), red, laminated, calcareous	0 to 15	
4.	Gravel, *Olean*, medium-grained, stratified	10 to 15	
5.	Peat, brown, compact	2 to 4	
6.	Till, *Illinoian*, blue-gray, weathered	0 to 8	
	Total	17 to 98	

the Binghamton deposits were to be correlated with either the Tazewell or Cary sub-stage and those of the Olean sub-stage with either the Iowan or Tazewell sub-stage. Because of the striking difference in the amount of weathering on nearby deposits of Olean, Binghamton and Valley Heads age (p. 38), and because each has formed a separate and distinct outwash terrace or valley train (p. 77), the writer believes that they represent three distinct glacial sub-stages. The Olean, Binghamton and Valley Heads sub-stages are, then, probably to be correlated with the Iowan, Tazewell and Cary sub-stages of the Upper Mississippi Valley respectively, as has been suggested by Flint (1947).

The Illinoian till and its related glacio-fluvial gravels are distinctly more weathered than any similar Wisconsin deposits. In most places the Illinoian deposits show no signs of a morainal topography, but in some areas where gravelly deposits, which were presumably kames, occur, occasional shallow, undrained depressions and small areas of gently rolling topography still exist. These facts prompted Leverett (1934) to correlate these deposits with the Illinoian deposits of the Upper Mississippi Valley, even though many miles separate the areas of occurrence in Pennsylvania from those to the west. Even in Pennsylvania, it is impossible to trace the deposits across the Appalachian Plateau. Undrained depressions occur in two areas of Illinoian glacial deposits along the Susquehanna River: one mile west of Selinsgrove (m.116) and one mile north of Dewart, on the West Branch (m.141). At both of these places the Illinoian gravel is so thoroughly weathered that it is not possible to determine whether the original deposit was gravel or till. Both of these places are underlain by calcareous shale or limestone. The closed depressions and undulating topography may, then, be either a relic of the Illinoian morainal topography or have been produced by the solution of the underlying rock. These facts do not, however, detract from the accuracy of Leverett's conclusion that these glacial deposits are Illinoian in age.

Glaciations earlier than the Illinoian may have reached Pennsylvania, as is indicated by some of the higher terraces (p. 118). Leverett (1902) reported evidence of a Kansan glaciation in northwestern Pennsylvania. He also discussed the occurrence of gravelly clay and scattered boulders beyond the limits of the Illinoian glaciation which had been interpreted as remnants of a Kansan till by Williams (1917), but which Leverett (1934) considered to be of doubtful significance. Inspection of these deposits by the writer yielded no definite proof that they are made of till and represent glaciation of Kansan or other age. However, they have been insufficiently studied and may eventually be interpreted as glacial outwash. If these deposits are glacial some of them might be Nebraskan, but no tangible evidence of Nebraskan glaciation has been recorded.

WISCONSIN GLACIAL STAGE

General Features.

The Wisconsin ice entered Pennsylvania from the north in three major ice streams (fig. 5, p. 16), as previously pointed out by Lesley (1884), Williams (1917), and MacClintock and Apfel (1944). In northwestern Pennsylvania and western New York the till and outwash are characteristically calcareous and contain about 2 per cent of red granite pebbles and few if any gneisses, as is shown in Table 1 of MacClintock and Apfel (1944). It is obvious that deposits of this lithologic character could be derived only from Ontario. Eastward, in northern Pennsylvania, between the Salamanca re-entrant and the North Branch of the Susquehanna River, the glacial deposits are characteristically only slightly calcareous or even noncalcareous and contain pebbles of gneiss and basic igneous rocks (p. 21 and Table 3, p. 18). Such material can be derived only from the Mohawk Valley and the Adirondack Mountains. In northeastern Pennsylvania, i. e. north and northeast of Pittston (m.193), the glacial deposits are characteristically feebly calcareous and contain pebbles of sedimentary rocks of Devonian age. They are free of limestone and of igneous or metamorphic rocks (p. 25 and Table 3, p. 18). It is obvious that such material can have been derived only from the direction of the Catskill Mountains and the Hudson River Valley.

In view of this evidence three major directions of ice advance are postulated: (1) from central Ontario, south and southeast; (2) from the general direction of the Adirondacks, south and southwest; and (3) from the Hudson Valley by way of the Catskills, south and southwest; as shown in Figure 5, (p. 16).

When the ice advanced from the lowlands of central New York onto the Appalachian Plateau and crossed the drainage divide, it thereafter flowed in valleys which trended in its general direction of flow and caused it to assume some of the characteristics of mountain glaciers. The normal smooth, arcuate curve common to an ice lobe in smooth country, and which the ice may have had as it advanced southward across New York, was moulded by the valleys into tongues of ice from two to ten miles long. These tongues advanced along the major valleys. The ice acted as dams to the waters of tributaries which, with melt water from the ice, flowed between the ice tongues and the valley walls. Thus kame terraces are well developed in every major valley, and the quantity of coarse glacial gravels which the marginal streams carried was more than adequate to bury any till which might have been deposited at the ice edge. Today the valley of the North Branch of the Susquehanna is broad and covered with outwash deposits. Any moraine which may once have been there has since been swept away. On the steep valley walls there are few signs of irregular, morainal topography. However, in small valleys, areas of till with morainal topography are found. Continuous moraines cannot be traced across the upland from valley to valley. The slopes of mountains and uplands are now smooth. The smooth slopes on the upland lie adjacent to morainal topography in the valley. One must assume that, in the initial configuration following the disappearance of the ice, morainal topography was continuous across the upland. The existing smooth slopes must be the result of the removal of till on the upland by an erosional process. As will be shown on page 56, this process was intense frost action including mud flowage and congeliturbation. Erosion of this type is general in the region, hence morainal

TABLE 3. *Pebble Counts of Pleistocene Deposits in the Susquehanna Valley*

Age	Valley Heads						Binghamton						
Material	valley train gravel	valley train gravel	valley train gravel	valley train gravel	valley train gravel	valley train gravel	kame gravel	till	valley train gravel	valley train gravel	valley train gravel	valley train gravel	valley train gravel
Locality	Milltown, N. Y.	Athens	Hornbrook	East Towanda	Wyalusing	Forty Fort	Greens Landing	Greens Landing	Standing Stone	Meshoppen	Falls	Selinsgrove	Highspire
Miles from Mouth	283	281	269	262	243	186	273	278	271	228	200	115	63
Pebble type (in per cent)													
Gray sandstone & siltstone	56.8	37.7	48.5	40.x	48.1	34.8	68.6	83.2	58.4	51.7	51.0	63.7	43.2
Red sandstone & siltstone	3.3	10.x	7.7	10.5	3.7	4.3	4.4	3.1	3.6	3.9	10.9	8.7	8.7
White sandstone	x	3.0	6.3	2.3	x	1.4	x	3.8	x	0.6	1.4	1.1	13.0
Gray slate	x	x	x	x	x	x	x	x	x	x	x	x	x
Black shale & siltstone	x	x	x	x	x	x	x	x	x	x	x	x	1.4
Blue limestone	21.9	16.9	13.1	18.4	17.3	0.6	12.2	13.8	11.6	9.3	10.7	x	x
Other limestone	x	9.1	14.4	3.x	x	5.5	3.0	4.7	7.3	8.6	3.8	x	x
Chert	3.1	9.1	4.5	9.2	8.8	12.2	3.0	1.5	12.1	4.7	2.8	7.0	10.8
Conglomerate	x	1.5	x	0.4	x	x	x	1.5	x	x	0.4	5.2	x
Coal	x	x	x	x	x	x	x	x	x	x	x	4.5	x
Quartzite	7.5	3.8	x	3.8	10.x	33.3	x x	1.8	8.3	11.5	12.2	7.6	17.1
Granite & gneiss	3.0	7.3	3.1	7.8	7.4	6.4	x	2.0	3.4	2.2	2.3	0.5	3.7
Quartz	x	x	0.9	x	x	x	x	x	x	x	x	0.5	2.1
Others	x	x	x	x	x	x	x	x	0.4	x	x	0.1	1.2
Total per cent	99.1	100.4	99.1	99.4	99.7	99.7	99.6	99.4	99.3	99.1	99.8	99.1	99.4
Total pebbles	115	233	220	317	363	139	179	188	224	299	211	171	253

Age	Olean										
Material	till	till	till	valley train gravel	till	till	kame gravel	kame gravel	valley train gravel	kame gravel	valley train gravel
Locality	North Towanda	Sugar Creek	Myersburg	Horton Corner	Meshoppen	Mehoopany	Lovelton	East Lemon	[illegible]	South Eaton	Falls
Miles from Mouth	268	267	260	247	228	235			233	206	203
Pebble type (in per cent)											
Gray sandstone & siltstone	84.0	11.3	88.9	76.0	56.3	37.4	50.2	63.6	61.4	68.0	60.7
Red sandstone & siltstone	4.0	14.6	3.1	6.4	21.1	37.0	45.1	35.6	26.0	18.5	11.7
White sandstone	x	x	x	x	x	x	x	x	x	x	x
Gray slate	x	x	x	x	17.8	x	x	x	x	x	x
Black shale & siltstone	x	x	x	x	x	x	x	x	3.0	x	x
Blue limestone	4.0	2.7	0.6	2.9	0.7	x	x	x	0.8	x	4.6
Other limestone	x	x	4.4	4.6	x	x	x	x	0.4	4.1	2.3
Chert	x	3.6	x	4.1	0.7	1.8	2.2	present	1.3	3.4	3.5
Conglomerate	x	x	x	1.1	x	x	x	0.7	7.6	x	x
Coal	x	x	x	x	x	x	x	x	x	x	x
Quartzite	6.0	0.9	2.4	3.4	x	0.9	1.8	x	3.0	4.0	3.3
Granite & gneiss	2.0	3.6	x	2.9	x	1.4	0.6	x	1.3	1.1	6.0
Quartz	x	x	x	x	x	x	x	x	x	x	x
Others	x	x	x	x	x	0.9	x	x	x	x	x
Total per cent	100.0	99.6	99.4	99.4	99.8	99.8	99.8	99.9	99.8	99.2	99.6
Total pebbles	100	109	156	170	140	210	217	138	221	175	214

Age	Olean										
Material	till	kame gravel	kame gravel	valley train gravel	valley train gravel	kame gravel	valley train gravel	kame gravel	kame gravel	till	valley train gravel
Locality	[illegible]	Hemlock Creek	Hemlock Creek	Hicks Ferry	Beach Haven	Beach Haven	Berwick	Fishing Creek	West Branch Glen Mawr	West Branch Pottery Rocks	West Branch Dewart
Miles from Mouth	186	174	170	167	163	163	135	134	167	133	140
Pebble type (in per cent)											
Gray sandstone & siltstone	67.3	70.6	71.2	81.5	56.2	66.4	72.7	54.6	37.8	53.5	63.6
Red sandstone & siltstone	14.5	18.9	17.4	16.0	37.0	15.7	11.1	38.6	61.4	40.7	5.0
White sandstone	x	x	x	x	1.8	x	1.0	x	x	x	14.5
Gray slate	x	8.5	1.7	x	x	6.5	x	x	x	1.1	6.9
Black shale & siltstone	4.3	x	x	x	2.0	0.7	x	x	x	x	5.4
Blue limestone	x	x	x	x	x	x	x	x	x	x	x
Other limestone	x	x	x	x	x	x	x	3.3	x	x	x
Chert	present	x	x	x	x	x	x	0.8	x	x	0.6
Conglomerate	3.6	x	1.1	1.0	x	7.8	2.2	2.1	1.8	2.1	2.6
Coal	7.7	x	4.0	1.0	x	x	1.1	x	x	x	x
Quartzite	2.1	7.8	2.2	x	1.2	1.0	2.7	0.4	0.7	x	1.1
Granite & gneiss	0.7	x	x	x	x	7.1	x	x	x	x	x
Quartz	x	x	x	0.5	1.6	x	0.1	x	x	x	x
Others	x	x	x	x	x	x	x	x	x	x	x
Total per cent	100.4	99.8	99.6	100.0	99.4	99.4	99.7	99.8	99.6	99.5	99.8
Total pebbles	138	164	171	200	147	125	180	238	110	142	158

Age	Illinoian						Pre-Illinoian	
Material	valley train gravel	valley train gravel	valley train gravel	valley train gravel	valley train gravel	gravel	gravel	gravel
Locality	[illegible]	New Columbia	Selinsgrove	Port Treverton	Marietta	Thompsontown Juniata River	Mexico	Conowingo, Md.
Miles from Mouth	184	156	115	111	46	104	114	3
Pebble type (in per cent)								
Gray sandstone & siltstone	43.7	47.7	41.8	36.6	74.6	33.7	x	x
Red sandstone & siltstone	2.0	4.2	11.5	7.4	3.3	30.9	4.7	x
White sandstone	57.0	3.1	0.4	5.7	x	13.1	11.9	x
Gray slate	x	31.6	26.9	1.4	1.1	1.2	x	x
Black shale & siltstone	x	x	4.1	7.7	8.4	x	x	x
Blue limestone	x	x	x	x	x	x	x	x
Other limestone	x	x	x	x	2.1	x	x	x
Chert	x	7.4	6.0	27.8	11.4	11.8	15.1	x
Conglomerate	1.0	1.3	x	x	0.1	1.5	7.4	x
Coal	x	x	x	x	x	x	x	x
Quartzite	x	3.6	9.6	5.1	14.8	7.3	18.7	21.0
Granite & gneiss	x	x	x	3.9	7.1	x	x	x
Quartz	x	x	x	0.7	1.4	x	x	78.x
Others	x	x	x	x	0.5	x.1	0.8	x
Total per cent	99.7	99.8	99.7	99.1	99.8	99.1	99.7	99.5
Total pebbles	98	143	167	111	130	101	111	191

topography is rare. Fluvial erosion, such as gullying on the interfluves, was relatively unimportant. However, as previously explained, the general absence of moraines on the Susquehanna and its major tributaries is due to the continuous removal, by meltwater, of till adjacent to the narrow tongues of ice which occupied the valleys.

Deposits of the Binghamton Sub-Stage.

The youngest glacial deposits in this part of Pennsylvania are those of the Binghamton sub-stage. The Binghamton ice moved southward from the Chemung Valley and extended down the Susquehanna to the vicinity of Milan (m.276). The ice limit is represented by a body of till which lies against the hills on the right bank of the North Branch between Milan and Greenes Landing (m.278). Here hills of till rise to broadly rounded tops, 140 feet above the river. Their topography is distinctly subdued and a considerable modification of their initial shape must be assumed.

The till is sandy or silty with few boulders and is oxidized to a depth of 9 feet and leached to a depth of 10 feet below the surface. It contains Grenville pebbles, as shown in Table 3, (p. 18) and one must assume that it was deposited by ice which had moved past the Adirondacks. A bank about 20 feet high, at Greenes Landing (m.278) on the south side of Murray Creek, west of the bridge on U. S. Highway 220, exposes typical Binghamton till (Table 4, p. 19). At the base are 6 feet of blue-gray, unleached and unoxidized, sandy till, estimated to consist of: silt and clay 10 per cent, fine sand 50 per cent, pebbles 30 per cent, and boulders and cobbles 10 per cent. As shown in Table 3, (p. 18) a pebble count gives 62 per cent of gray siltstone and sandstone, 18 per cent of limestone, and 2 per cent of granite and gneiss. Such a distribution of lithologic types is characteristic of deposits of the Mohawk Valley lobe and, as is shown in Table 3, (p. 18) is distinctly different from that of the Olean till which is exposed at Sugar Run (m.267) a few miles to the south. The unweathered till is overlain by 6 feet of oxidized till, from the upper 5 feet of which the carbonates have been leached. Above the weathered till there is a mass of silty till containing unoriented, striated pebbles. It is irregular in thickness, ranging from 3 to 6 feet. This material appears to be a silt mixed

TABLE 4. *Geologic Section on Right Bank of Murray Creek at Bridge of U. S. Highway 220, Greenes Landing (m.278), Sayre, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loess, *Binghamton*, buff, loose, pebbly, leached, oxidized; contains unoriented, platy pebbles; tends to break into small, horizontally oriented, lenticular flakes	6	0
2.	Till, *Binghamton*, buff, compact, sandy, leached, oxidized; contains striated pebbles and cobbles; pebbles covered with black stain	3	0
3.	Sand, *Binghamton*, black, medium-grained, leached, oxidized	0	6
4.	Till, *Binghamton*, buff, compact, sandy, leached, oxidized	1	6
5.	Till, *Binghamton*, buff, compact, sandy, calcareous, oxidized	1	0
6.	Till, *Binghamton*, blue-gray, compact, sandy, calcareous, unoxidized; contains abundant striated pebbles and cobbles; in sharp contact with horizon 5. Exposed	6	0
	Total	18	0

Depth of leaching: 11 feet
Depth of oxidation: 12 feet

with till, rather than a silty phase of the till or a weathered zone. The silty zone cannot be correlated with any local alluvial surface, and it is probably the result of combined wind deposition and frost action, as explained on page 51.

The Binghamton kame gravels have the same lithologic composition and essentially the same depth of leaching and oxidation as the till. They are characteristically overlain by a few inches of buff, loess-like, pebbly silt which the writer believes was, in part, windborne (p. 48).

Deposits of the Olean Sub-Stage.

During the Olean sub-stage, ice covered the northeastern, and most of the north central, parts of Pennsylvania. Its southern limit, which extends irregularly from Olean, New York, to Belvidere, New Jersey, is essentially the "Terminal Moraine" as mapped by Lewis and Wright (1884). There is, however, no continuous belt of morainal topography, but rather bodies of till or kames with morainal topography in the valleys separated by relatively smooth-surfaced interfluves. Minor revisions in mapping have since been made by Williams (1895) and by Leverett (1934). This revised boundary is shown in Figure 5. The boundary crosses the North Branch of the Susquehanna River near Berwick (m.158), where there is a body of coarse kame gravel lying near the present river level. West of Berwick the boundary crosses several tributary creeks of the North and West Branches of the Susquehanna.

The Olean glacial deposits have been studied by a number of geologists whose findings are in accord with the observations here recorded. Fuller and Alden (1902) found the till near the New York state line to be sandy and full of angular fragments of local rock, with few foreign boulders. Branner (1886) and Darton (1914) described the till in the Wyoming-Lackawanna Basin as containing 50 per cent sand and as composed predominantly of fragments of Pocono sandstone, Pottsville conglomerate, and various Carboniferous shales, sandstones and also coal, with lesser amounts of "Catskill" shale and with very few igneous or metamorphic rocks. According to Itter (1938), crystalline rocks are found in the Olean gravel of the Wyoming Valley, but not in that of the Lackawanna Valley. Thus he anticipated the lithologic division of Olean deposits here set forth.

The Olean till and gravel may be divided into two phases or types on the basis of lithologic composition (Table 3, p. 18). One contains not only pebbles of pink granite, pink gneiss, and other igneous and metamorphic rocks, but also blue limestone pebbles from the Mohawk Valley, and, therefore, is derived from ice which moved southward from western New York. The other consists largely of sandstone and shale fragments and contains no igneous or metamorphic pebbles and no blue limestones. It is probably derived from ice which moved southwestward from the Hudson River Valley, across the Catskills and into Pennsylvania. Such a division of the ice tongues, as is here postulated, was previously made by Lesley (1884) and Williams (1917) on the basis of the pattern of the "terminal moraine" and the major topographic features of the region.

TABLE 6. *Summary of Igneous and Metamorphic Pebbles Found in the Till and Gravel of the Susquehanna Valley.*

LOCALITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AGE	Valley Heads	Valley Heads	Binghamton	Valley Heads	Olean	Valley Heads	Binghamton	Olean	Olean	Olean	Olean	Binghamton	Valley Heads	Olean	Olean	Binghamton	Illinoian	Binghamton	Illinoian
FIELD DESCRIPTION																			
Quartzite, blue-gray to black, macrocrystalline, banded with thin, dark, parallel, lenticular bands. Has white weathered crust.					10	2	1	2		4			1		5			2	3
Quartzite, gray, banded, garnetiferous.					1					1									
Quartzite, pink, with crystals or laminae of pink feldspar.									1				1			1			
Schist, black, micaceous.																		1	3
Augengneiss, gray, with thin, black, micaceous bands and porphyroblasts of feldspar.									3										
Granite gneiss, pink, medium to fine-grained. Quartz concentrated in thin, parallel bands. Weathers to tan color.	1	10	2	7	10	12		8	5	8	3	5	8	3	4		4	17	
Granite, pink, fine to coarse-grained, contains biotite and sometimes tourmaline or hornblende.	2	7	2		11	1	6	4	1			2	1	3	1	1		16	2
Granite, gray, medium to fine-grained, contains biotite.					4		2	2					2	2	1				
Syenite, pink, coarse-grained, containing 15 to 25 per cent of dark mineral and less than 10 per cent quartz.								2	3										
Syenite, gray, with hornblende or hypersthene.					1										1				
Anorthosite, dark gray, medium-grained.																		2	
Diorite, fine-grained, dark gray.							1	1	1										
Granophyre, brilliant red.																		5	
Aplite, tan to gray, aphanitic, with brown feldspar crystals and quartz masses.																1			
Felsite porphyry, dark green to black, with white or brown feldspar phenocrysts. Some contain epidote.										3				1	1				
Felsite porphyry, reddish-purple, with medium-grained phenocrysts of pink feldspar.					7													3	
TOTAL	3	17	4	7	44	15	10	19	14	16	3	7	13	9	13	3	4	46	8

The general properties of the till of the Mohawk Valley ice tongue are best illustrated by a section (Table 5, p. 21) exposed in an 80-foot bank on the north side of Mehoopany Creek, 1¼ miles west of North Mehoopany (m.225). Here the till is compact, sandy and contains boulders over 2 feet in diameter, as well as pebbles and cobbles, in a fine to very fine sand matrix. It has a brown color with a reddish to pink cast. Above the exposure the slope rises at an angle of about 15 degrees; below it there is an almost vertical cliff where Mehoopany Creek has cut into "Catskill" sandstone. In this section the Olean till, 48 feet thick, is overlain by loess onto which a body of till and loess has slid from higher up the slope. The significance of the upper horizons in this section is discussed on page 58.

TABLE 5. *Geologic Section on Right Bank of Mehoopany Creek, 1¼ Miles West of North Mehoopany (m.225), Meshoppen, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Congeliturbate, *Binghamton* (?)		
a.	Loess, *Olean*, buff, loose, silty, stony, leached, oxidized	1 to 2	0
b.	Till, *Olean*, buff, loose, sandy, silty, leached, oxidized; contains boulder concentration; open voids	3	0
c.	Till, *Olean*, red, sandy, bouldery, leached; open voids	2	0
2.	Loess, *Olean*, buff, pebble-free, leached, oxidized; occurs in pockets	0	6
3.	Till, *Olean*, red, sandy, leached	8	0
4.	Till, *Olean*, red, sandy, slightly calcareous	8	0
5.	Till, *Olean*, red, clayey, jointed	7	0
6.	Till, *Olean*, red, silty; contains striated cobbles. Exposed	23	0
7.	Covered, about	25	0
	Total	78	0

Depth of leaching: 15 feet
Depth of oxidation: obscure, at least 15 feet

The till is composed chiefly of local rocks from the Appalachian Plateau, mostly red and gray sandstone and siltstone. A pebble count (Tables 3 and 6, pp. 18, 20) shows the presence of two rocks which are characteristic of the deposits of the Mohawk Valley tongue throughout eastern and central Pennsylvania. They are: a fine-grained, banded, pink granite gneiss; and a banded, black quartzite whose surface is commonly weathered to a thin, white crust. Microphotographs of these rocks are shown in Figure 6, (p. 24). (Similar pebbles are described in detail on page 24.) The average composition of the Mohawk till along the North Branch of the Susquehanna River is shown by pebble counts, at Mehoopany Creek (m.225), at Sugar Run (m.267) 28 miles to the north, and at Luzerne (m.186) 33 miles to the south, which are recorded in Table 7, (p. 22). This table shows that there is a general tendency for the proportional content of igneous and metamorphic pebbles to decrease from north to south. The rate of decrease in crystalline pebble content is of the order of 0.07 per cent per mile.

The influence of change in the lithology of the country rock on the composition of the till may also be seen from Table 3, (p. 18), for between Sugar Creek (m.267) and Mehoopany Creek (m.225) the bedrock, and also the predominant rock in the till, change from gray sandstone and siltstone to red sandstone and siltstone; and between Mehoopany Creek and Luzerne (m.186) the change is reversed. These changes in composition as reflected in the soils were recognized by

Shaw and others (1914). They distinguished the Volusia soils, derived from gray till, from the Lackawanna soils, derived from red till. Present studies serve to show the order of magnitude in the rate of change of till composition. Along the Susquehanna River the components derived from local rock increase in the direction of ice movement in proportion at a rate which is of the order of 0.7 per cent per mile, and the other components decrease proportionately. However, the Appalachian Plateau rocks characteristic of the whole area remain essentially constant at 90 to 95 per cent with respect to the rocks carried into the area from central and northern New York. Table 7, (p. 22) contains a comparison of composition calculated from this empirical relationship and observed composition along a 76-mile line normal to the ice boundary. This line is assumed to be parallel to the movement of the ice. North of the "Catskill Scarp" and south of the Allegheny Front the country rock is predominantly gray colored; red rocks predominate in the intervening area. At these points there is a change from increasing gray rocks to increasing red rocks, or vice versa.

TABLE 7. *Calculated and observed composition of Olean till along a 76-mile glacial flow-line.*

PLACE	Sugar Creek	Catskill Scarp	Mehoopany Creek		Allegheny Front	Luzerne	
DISTANCE IN MILES	0	7	29		40	76	
	per cent						
COMPOSITION	obs.	calc.	calc.	obs.	calc.	calc.	obs.
Gray sandstone & siltstone	65.0	69.9	54.5	55.4	46.8	59.4	67.3
Red sandstone & siltstone	25.8	20.9	36.3	39.0	44.0	31.4	14.5
Chert	3.6	3.2	1.9	1.8	1.3	0.6	present
Limestone	2.7	2.3	1.0	0.0	0.4	0.0	0.0
Crystalline rocks	3.6	3.2	1.9	2.7	1.3	0.6	0.7
Total	100.7	99.5	95.6	98.9	93.8	92.0	82.5

Wherever a thick deposit of till is exposed, as at Mehoopany Creek (m.225) (Table 5, p. 21), and Luzerne (m.186) (Table 8, p. 22), it is

TABLE 8. *Geologic Section in Road Cut and Gravel Pit on West Side of Highway 309 at Luzerne (m.186), Pittston, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loess, *Binghamton* (?), black, loose, non-calcareous, oxidized	0	1
2.	Loess, *Binghamton* (?), dark brown, loose, pebbly, non-calcareous, oxidized	0	4
3.	Loess, *Binghamton* (?), light brown, slightly compact, pebbly, non-calcareous, oxidized	0	3
4.	Sand, *Olean*, light brown, compact, silty, non-calcareous, oxidized	0	10
5.	Gravel, *Olean*, gray to brownish-gray, medium-grained, non-calcareous, oxidized; in matrix of medium-grained sand; contains coal-bearing layers near base	33	0
6.	Silt, *Olean*, light brown, pebble-free, non-calcareous, oxidized; contains 1-inch black to dark brown zone 6 inches below top	1	4
7.	Sand, *Olean*, greenish-gray, fine-grained, non-calcareous, oxidized	0	10
8.	Till, *Olean*, brown, sandy, non-calcareous, oxidized	0	6
9.	Till, *Olean*, orange-brown to reddish-brown, feretto zone, non-calcareous, oxidized; an irregular zone near the till-sand contact, elsewhere entirely within the sand	2	0
10.	Till, *Olean*, blue-gray, sandy, non-calcareous, unoxidized	25	6
11.	Till, *Olean*, blue-gray, clayey, non-calcareous, unoxidized; contains some sand. Exposed	15	0
	Total	79	8

Non-calcareous
Depth of oxidation: 39 feet

not homogeneous, but is divisible into an upper sandy till and a lower clayey till. At Luzerne the upper zone is composed of 28 feet of unoxidized, blue-gray, sandy till containing some silt. The lower zone, of which 15 feet is exposed, consists of unoxidized, blue-gray, clayey till containing some sand grains. At Mehoopany Creek the upper zone is 16 feet thick and consists of brown to reddish-brown, compact, sandy till containing pebbles, cobbles and boulders up to 2 feet in diameter, and a fine to very fine sand matrix. Striated pebbles are rare. When rolled in the fingers the till will not slick, but crumbles. This is taken to indicate that it is poor in silt and clay sizes. The lower zone consists of 7 feet of reddish-brown, jointed, clayey till underlain by reddish-brown, compact, silty till of which 23 feet is exposed. Striated pebbles are common. The red color of the till is due to the high content of "Catskill" pebbles. This gives the till a pink cast which is different from the deep reddish-brown produced by the weathering of Illinoian deposits. In both localities the upper zone resembles superglacial till and the lower zone basal till, as described by Flint (1947) and others, and they are so identified by the writer.

The glacial outwash gravels which occur in ice-contact deposits along the Susquehanna Valley are divisible, by their sorting and coarseness, into two categories: (1) coarse-grained, poorly sorted gravel, and (2) medium- to fine-grained, well sorted gravel. The coarse, poorly sorted gravels were, in all instances, deposited at or near the edge of the ice. For this reason they are here referred to as "kame gravels". They occur in marginal kames in the smaller tributary valleys and in the "gravel moraines" which represent still stands of the retreating ice front. The fine-grained, well sorted gravels resemble those of an ordinary valley train and, hence, are referred to as "valley train gravels". They occur in the Susquehanna Valley, particularly at the junction of the Chemung (m.278) and Lackawanna (m.193) rivers.

Gravel moraines occur in the valley bottoms and presumably were once continuous with an irregular deposit of till on the mountain slopes. The morainal topography of the latter has, in most places, disappeared, in the manner previously described on page 18, whereas the gravels, because of their greater permeability and more stable slopes, have been preserved and still retain some irregular topography.

The kame deposits are illustrated by a section in a gravel pit on the north side of Highway 87, 1½ miles east of Forkston (Table 9, p. 23).

TABLE 9. *Geologic Section in Road Cut on Highway 87, 1¼ Miles East of Forkston, Meshoppen, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loess, *Binghamton* (?), buff, leached, oxidized; contains angular cobbles	3	0
2.	Rubble, *Binghamton* (?), buff, silty, leached, oxidized; composed of angular cobblestones; open voids	2	6
3.	Gravel, *Olean*, brown, coarse-grained, poorly sorted, sandy, leached, oxidized; composed of rounded pebbles and cobbles	6	0
4.	Sand, *Olean*, brown, very fine-grained, pebble-free, leached, oxidized; in sharp contact with horizon 5	9	0
5.	Gravel, *Olean*, red to reddish-brown, coarse-grained, silty, leached	2	6
6.	Gravel, *Olean*, red to reddish-brown, coarse-grained, silty, calcareous, unoxidized. Exposed	12	6
7.	Covered, to base	10	0
	Total	45	6

Depth of leaching: 22 feet
Depth of oxidation: about 20 feet

Here coarse, poorly sorted Olean gravel at least 30 feet thick, with lithologic composition typical of the deposits of the Mohawk tongue (Table 3, p. 18), is overlain by a thin body of rubble composed largely of disturbed till which has moved down over the kame from the adjacent mountain slope. Above this is a layer of buff, loess-like silt containing angular cobblestones. As discussed on page 51, such loess-like silts containing pebbles or larger stones are believed to be wind-borne deposits which have gained the stones from below by frost-heaving.

Similar deposits of kame gravel occur on the so-called "terminal moraine" of the Olean ice near Berwick (m.158). The gravel is exposed in a pit on the north side of U. S. Highway 11, ¾ mile west of Beach Haven (m.161). Here, near the highway, there is a deposit of coarse gravel which is 8 to 10 feet thick and is underlain by 5 feet of silt lying upon black shale. Toward the north the silt and shale pass below the base of the exposure and the entire 18 feet of the cut is made up of coarse gravel. This gravel is non-calcareous and has, at a depth of 7 to 8 feet, an iron-stained zone. The igneous and metamorphic pebbles found here (Table 6, p. 20) include: (1) a blue-gray or black, microcrystalline quartzite with dark, parallel, lenticular bands, $1/32$ to $1/64$ inch wide and ¼ to ½ inch long; the surface is weathered, to a depth of about $1/32$ inch, and this crust consists of a white, sugary layer through which the dark bands rise as small ridges (fig. 6-A, p. 24); (2) a fine-grained, pink granite gneiss in which the quartz is arranged in thin, parallel bands; some pebbles with prominent bands of biotite (fig. 6-B, p. 24); (3) a green, porphyritic felsite containing small phenocrysts of feldspar $1/32$ inch in diameter. Similar pebbles are found in the kame gravels at Forkston and in the till at Mehoopany Creek and Sugar Run (Table 6, p. 20), but not in the deposits of the Hudson Valley tongue. For this reason the Beach Haven deposits are attributed to the Mohawk tongue.

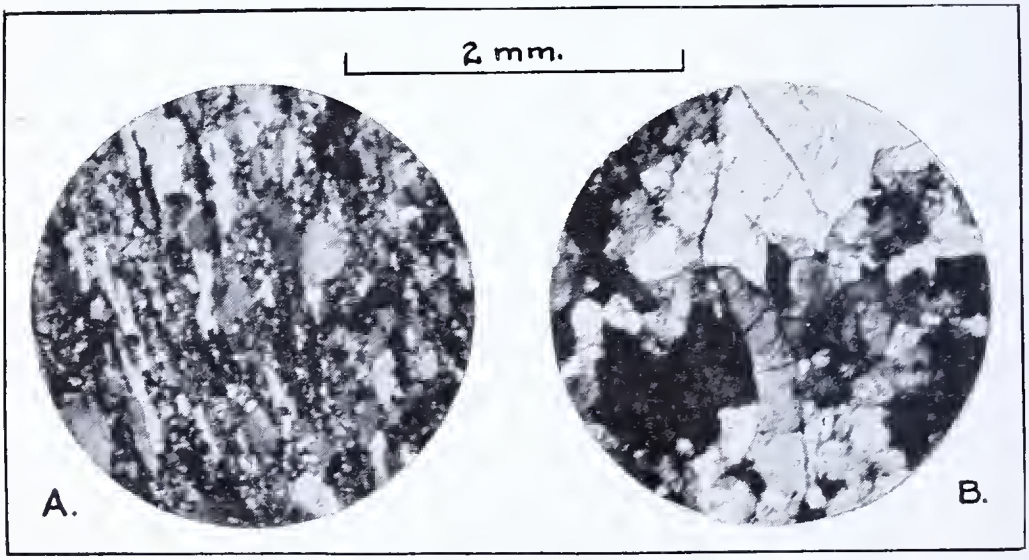

FIGURE 6—A. Microphotograph of banded black quartzite pebble. Crossed nicols.
B. Microphotograph of pink granite gneiss pebble. Crossed nicols.
(Scale indicated by 2 mm. scale to same magnification.)

The till of Hudson type in this region is generally sandy or silty, non-calcareous or weakly calcareous, and is composed entirely of rocks from the Appalachian Plateau. It is found in the area east of the North Branch of the Susquehanna River between Scranton and Meshoppen and probably extends eastward to the Delaware Valley. The nature of this till is illustrated by a cut in a hill on the west side of U. S. Highway 6 at Meshoppen (m.228). Here, about 50 feet of brownish-red, stony, silty till, leached to a depth of 20 to 25 feet, is exposed. A count of pebbles from this till (Table 3, p. 18) shows a dominance of sandstone from the Appalachian Plateau and an absence of crystalline rocks. The lithologic composition of this till is so different from that of the till near North Mehoopany, 6 miles to the south (p. 21), that one must conclude that these two tills were deposited by ice that came from somewhat different directions or by different routes to the location of the deposit, and that they are the deposits of different tongues of ice.

At East Lemon, about 11 miles east of Meshoppen, the kame gravels of the Hudson Valley tongue have a composition which is similar to that of the till. Here, 15 feet of kame gravels are exposed in a road cut on the west side of Highway 92, 1 mile south of East Lemon. These gravels were derived entirely from local rocks (Table 3, p. 18). Igneous and metamorphic pebbles are absent.

The maximum advance of the Olean ice is represented by a "terminal moraine" in the neighborhood of Berwick (m.158) and Beach Haven (m.161). This moraine, previously described by White (1883), Lewis (1884), Williams (1895), and Leverett (1934), is a gravel moraine and is composed largely of poorly sorted, coarse kame gravel, medium-grained valley train gravel, and sand. These gravels were deposited in marginal channels between a stagnant tongue of ice, which lay in the center of the valley, and the valley walls, in the manner described by Woodworth (1905) for the deposits of the Hudson River Gorge. However, beyond the "terminal moraine", as is shown in Figure 33, (p. 91), the terraces composed of valley train gravel have a more gentle gradient than do the terraces of the higher-level, kame gravel deposits. During the early stages of kame terrace development the marginal channels flowed at a level which was high above the valley, and, at the front of the ice, fell sharply to the valley floor. At the ice front a steep alluvial deposit, composed largely of coarse gravel, was formed. Continued ablation of the ice in the valley probably caused the marginal streams to flow at successively lower levels. These streams, where they flowed along the ice, both eroded the earlier deposits and filled in their channels; where they crossed the "terminal moraine" they cut channels in the previously deposited alluvium and laid down sand and gravel on more gently sloping gradients toward the river valley beyond it. In this manner any till deposited at the ice front became buried or eroded. The successive gradients of these streams are shown in Figure 33, (p. 91). This feature of the ice edge is discussed in full on pages 91 to 97.

The distribution of kame gravel and till deposits indicates that the front of the ice tongue in the valley had a slope of about 150 feet per mile, or approximately 1.6 degrees, up to an elevation of about 250 feet above the river. This may be compared with the slope of the Olean ice front on Loyalsock Creek, a tributary of the West Branch 39 miles to the west, of 128 feet per mile, or 1.4 degrees. Above this point the slope decreases.

DEPOSITS OF THE ILLINOIAN STAGE

The Illinoian till, readily distinguished from Wisconsin till by its greater weathering, occurs as hilltop remnants in a narrow zone beyond the limits of the Wisconsin till. No Illinoian deposits have yet been found north of the limits of the Wisconsin glacial deposits in Pennsylvania. The Illinoian was first recognized by Wright (1892), who described it under the title of "extramorainic drift". He considered this to be the same as the "fringe" of Lewis (1884). However, Lewis described the "fringe" as limited to western Pennsylvania, and it seems more likely that he had reference, not to the Illinoian drift, but to the existence of a zone of relatively fresh igneous boulders, of probable Wisconsin age, unaccompanied by significant till deposits, which occurs in a belt 3 to 5 miles wide, beyond the Wisconsin terminal moraine. Such a "fringe" has not been observed east of the Salamanca re-entrant. Williams (1895, 1898, 1902, 1917) dealt largely with the pre-Wisconsin deposits which he called Kansan, but did not consider to be much older than the Wisconsin (1898). He considered the "terminal moraine" of Lewis and Wright (Lewis, 1884), i. e. the Olean border, to be a recessional moraine of which the "drift limits", i. e. the Illinoian, represented the terminal stage. Leverett (1934) divided the extramorainic drift, mapped by Williams (1895, 1917) into an Illinoian drift and a probable pre-Illinoian drift.

In the Susquehanna Basin, Leverett shows on his map (1934) four major projections of the Illinoian glacial boundary beyond that of the Wisconsin ice (fig. 5). These are the tongues at (1) English Center, (2) Williamsport (m.161) and Watsontown (m.138), (3) Rohrsburg, and (4) Selinsgrove (m.115). The boundary extends southward from the Olean glacial boundary to English Center on Little Pine Creek, then eastward to Field on Lycoming Creek. It then passes southward to the West Branch of the Susquehanna River near Montoursville (m.157). From here it projects as a narrow tongue up the West Branch past Williamsport (m.161). The boundary then follows around the eastern end of Bald Eagle Mountain (m.150). At the watergap in the Muncy Hills (m.144) the boundary is extended as a second tongue down the Susquehanna River to Watsontown. The boundary extends eastward from the Muncy Hills to Little Fishing Creek. Here it passes southward to Rohrsburg, thence eastward to the Olean glacial boundary. The Illinoian boundary is extended as another tongue along the Susquehanna River from Berwick to Selinsgrove, with a minor offshoot projected northward through the watergap of the West Branch at Winfield (m.127).

This boundary of the Illinoian, as mapped by Leverett, is a cautious estimate of the extent of the Illinoian ice in this region. Recent construction in White Deer Valley has shown that Illinoian ice passed over

Penny Hill (m.144) and covered most of the valley. Till along the West Branch south of White Deer Creek (m.138) is interpreted as Illinoian. Other exposures in the interfluve between the North and West Branches, north of Montour Mountain (m.128), indicate an additional expansion of the Illinoian ice limits there.

The revisions of Leverett's boundary are small, but they lead to the general conclusion that the distribution of Illinoian till in the valleys and its corresponding absence on the mountains should be considered the result of severe post-Illinoian erosion, particularly by congeliturbation, rather than an indication that these mountains were nunataks and projections above the level of the Illinoian ice sheet.

The glacial deposits along the West Branch between Watsontown (m.138) and Montour Mountain (m.128) and above Williamsport (m.161), previously mapped as pre-Illinoian deposits, are not more thoroughly weathered than the Illinoian deposits. One such deposit, shown in Figure 18 (p. 61), is well exposed in a road cut on Highway 220, 1/10 mile east of the bridge across Chatham Run at Charlton (m.184). Here a thick rubble deposit which, as will be shown on page 61 is probably divisible into portions of Wisconsin and Illinoian age, lies upon reddish-colored sand and gravel, which in one place grade downward into a gray, unoxidized horizon (Table 10, p. 27). No soil zone was found between the lower rubble and the sand and gravel, and the two are, therefore, presumably of the same age. As will be shown on page 61, this age is probably Illinoian. The gravel in this deposit is, like that on Pine Creek near Tomb (m.185) (Table 3, p. 18), composed largely of sandstone pebbles in a sandy matrix, and is quite different in lithology from the glacial deposits found near Selinsgrove (m.115). This difference probably accounts for their difference in appearance, for the gravel at Charlton is rusty-brown rather than brick-red in color. Other deposits, whose age is now debated, occur on the hilltops near Lewisburg (m.131). They are thin, buff-colored, silty gravel deposits, generally 1 to 3 feet in thickness. The pebbles or cobbles are largely the same sandstone or quartzite which make up the resistant pebbles in the nearby Illinoian till or kame gravel. As will be shown on pages 49 and 107, there was an appreciable amount of both sand and silt deposited by wind in this area during the Wis-

TABLE 10. *Composite Geologic Section in Road Cuts along Highway 220 on the east side of Chatham Run near Charlton, Lock Haven, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Rubble, *Wisconsin*, grayish-buff, unsorted, medium- to fine-grained, oxidized	4 to 6	0
2.	Rubble, *Illinoian*, reddish-brown, medium- to fine-grained, oxidized	0 to 18	0
3.	Sand, *Illinoian*, rusty-brown, fine-grained, clayey, oxidized	5	0
4.	Sand, *Illinoian*, rusty-brown, contains zones of cobbles or gravel, oxidized	10	0
5.	Sand, *Illinoian*, gray, very fine, unoxidized, non-calcareous, exposed	0 to 2	0
6.	Covered, to highway	0 to 3	0
	Total	19 to 41	0

Non-calcareous
Depth of oxidation: 36 feet

consin stage. The buff color of these gravel deposits is probably due to the accumulation of Wisconsin loess with which they became mixed by frost action. In this instance, the difference in appearance between these deposits and those previously identified elsewhere as Illinoian does not indicate a difference in age. It is, therefore, probable that these deposits were laid down during the Illinoian stage. Leverett's map shows a 5-mile gap of unglaciated territory along the West Branch between the Illinoian till mapped by him near Watsontown and that at Montour Mountain. The writer's interpretation of the deposits near Lewisburg eliminates the necessity of postulating such a gap, and one may assume that the Illinoian ice was continuous along the West Branch from Muncy to the mouth.

Weathered Illinoian till in the Susquehanna region was described by Leverett (1934) as clayey with a reddish color, which is decidedly in contrast with the yellowish-brown color of the oxidized portion of the neighboring Wisconsin till. It is best exposed in a road cut along Highway 404 at the top of Penny Hill. Here three horizons may be recognized, as shown in Figure 8, (p. 29): (1) brick-red, clayey, pebbly, oxidized till; (2) tan-colored, silty, pebbly, compact, jointed till; and (3) blue-gray, clayey, pebbly, unoxidized till. The pebbles in the upper horizon are largely buff siltstone coated with a brick-red, ocherous stain. Those in the lowest horizon are fresh, gray-colored and show striae. In pockets on the hilltop, shown in Figure 8 (p. 29), where bedrock reaches the surface, there are small, buff-colored deposits of pebbles and cobbles. These deposits are similar in appearance to those found near Lewisburg, described on page 27. The upper, red, clayey horizon is interpreted as the oxidized B-horizon of a soil which was formed during the Illinoian-Wisconsin interglacial interval, from which the A-horizon was removed by congeliturbation during Wisconsin time. Such erosion must be assumed in order to explain the continuous, unbroken surface across till and rock alike, as shown in Figure 8. The small quantities of buff-colored, silty soil which overlie the red, clayey till at the southern end of the exposure are probably loess of Wisconsin age which has moved down the slope as a congeliturbate.

Where the Illinoian till is thin and rubified (Movius, 1944) throughout, residual clay developed by the solution and weathering of the underlying limestone and shale is commonly developed at the base. This is shown (Table 11, p. 29) in a shallow pit on the west side of Highway 14, ½ mile north of Dewart (m.141). Here 10 feet of red, clayey, stony till lies over a 2- to 3-foot zone of red, pebble-free, residual clay, which rests on the rough and deeply pitted surface of the limestone. In such situations the post-Illinoian weathering appears to have penetrated the till mantle and attacked the relatively susceptible bedrock.

The terminal moraine of the Illinoian ice is now represented by an area near Selinsgrove (m.115) of subdued, gently rolling topography with shallow, undrained depressions. It is underlain by thick till and ice-contact gravel deposits composed entirely of local rocks (Table 3, p. 18). A road cut along U. S. Highway 522, 1¼ mile northwest of Selinsgrove shows (fig. 7, p. 29) as did a similar cut on Penny Hill

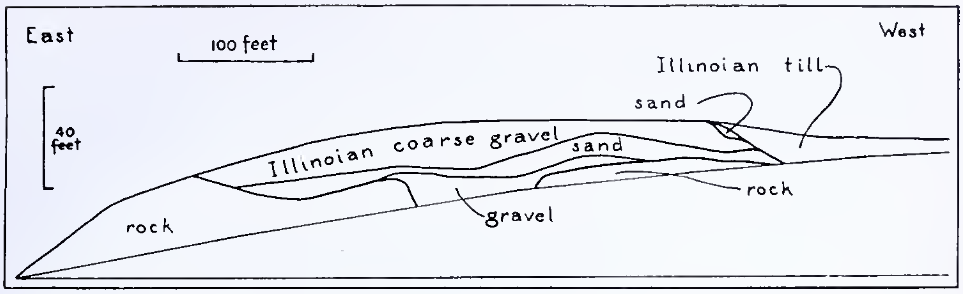

FIGURE 7. Geologic cross-section of hill near Selinsgrove as it is exposed in road cut along U. S. Highway 522. The absence of a break in slope at the contact between the rock and the Illinoian gravel is shown.

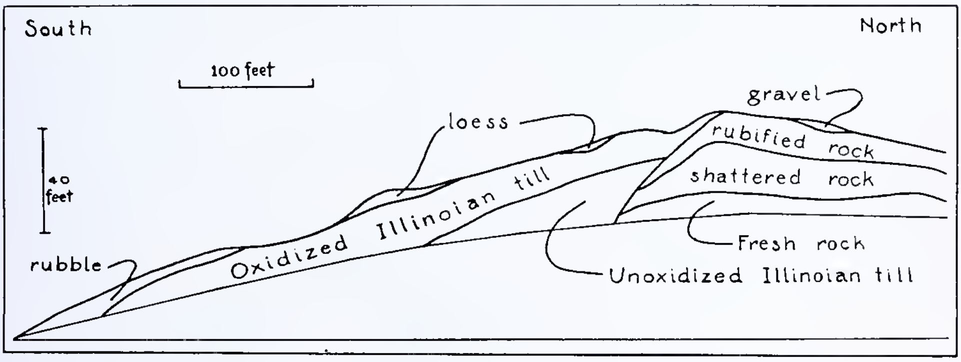

FIGURE 8. Geologic cross-section of Penny Hill on U. S. Highway 15 near Montgomery showing weathered zones in both the Illinoian till and the rock.

(p. 28), that post-Illinoian erosion has been severe and that the present topography may bear slight relationship to either the pre-Illinoian topography or the Illinoian glacial topography. Beneath the present hilltop there was formerly a valley which drained northward toward Penns Creek. It is filled with outwash gravel, above which there is a layer of sand and a thick deposit of coarse gravel. The gravel consists largely of weathered pebbles and cobbles of Devonian sandstone, siltstone and shale. The surface of the stones is either covered with a black stain or has a brick-red color. The deposit appears to have once been a gravel in a sandy matrix, but the introduction of clay, whose presence is attributable to weathering and soil processes, has changed the gravel to a compact, sticky, till-like material. Against

TABLE 11. *Geologic Section in Pit on Highway 405, ½ Mile North of Dewart (m.140), Milton, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Till, *Illinoian,* red, clayey, stony, non-calcareous, oxidized; composed chiefly of shale, sandstone, chert and quartzite	10	0
2.	Clay, *post-Illinoian,* red, pebble-free, non-calcareous; in places banded by weathering; a residual clay produced by weathering of the underlying rock	2 to 3	0
3.	Limestone, *Lower Devonian,* gray, fossiliferous; deeply pitted by solution. Exposed	3	0
	Total	15 to 16	0

Depth of leaching: 13 feet
Depth of oxidation: 13 feet

these deposits, on the western end of the cut, there is a deposit of till which is described in detail on page 44. As may be seen in Figure 7 (p. 29), the present surface cuts smoothly and without break in slope across the till, gravel and bedrock. Running water would not have eroded in such a manner, for its flow is related to the permeability of the underlying material and the position of the water table, and the contacts between different materials would have caused differential erosion. Gullies rather than a smooth, rounded slope would have been the result. Some other process must be invoked and, as will be shown later (p. 67), the most likely process is *cryoplanation.*[1]

PRESUMED GLACIAL DEPOSITS OF PRE-ILLINOIAN AGE

No unquestioned deposits of pre-Illinoian till were found along either branch of the Susquehanna River. Some of the materials previously attributed (Williams, 1917; Leverett, 1934) to a pre-Illinoian glaciation appear to be congeliturbates; others are probably Illinoian in age. Whether a pre-Illinoian ice invasion of the Susquehanna Valley can properly be postulated is a question requiring further study of widely scattered and obscure deposits of boulders, gravel, and till-like masses. Gravel deposits of pre-Illinoian age are described on pages 118 to 119.

WEATHERING

GENERAL STATEMENT

The soils of the area and the pebbles of the glacial deposits show that there is a distinct difference, in the amount and in the type of weathering, between deposits of different ages. These differences are used in the age discrimination between tills, valley train gravels and periglacial deposits of gravel and rubble.

Pebbles one to two inches in diameter, selected from deposits of till and gravel, may be classified, by their color and other reaction to weathering, into five groups:

(1) those which are strong, fresh, not discolored and, in the case of feldspathic rocks, those that have glassy feldspar crystals;
(2) those which are weathered to a buff color and, in the case of feldspathic rocks, those whose feldspar crystals are dull or chalky in appearance;
(3) those buff-colored pebbles of group 2 which are as a whole slightly weathered, but in which selected minerals have been deeply weathered, giving the pebble a spotted brown aspect and a lower crushing strength;
(4) those which are thoroughly weathered to a dark-brown color and, in the case of granitic pebbles, may be broken between the fingers; and
(5) those which have been weathered to a pink or brick-red color.

---

[1] *Cryoplanation* (see Bryan, 1946) is the process of the reduction of the land in which the primary agents are congelifraction and congeliturbation. It is supposed that on the mountain slopes of Pennsylvania this process predominated over those of the fluvial cycle during parts of each glacial stage.

These groups are not comparable to the five groups based on strength, used by MacClintock (1940), for group 4 is roughly equivalent to MacClintock's group 5 and many of group 5, here, would fall into MacClintock's groups 3 and 4. Group 3, here, would not constitute a separate group under MacClintock's classification, but would fall into his groups 2 and 3.

The distinctions, on the basis of color, used here, are essentially distinctions in the amount of iron which has been transformed into limonite and redeposited within the pebble. The distinction between the buff and brown pebbles on the one hand and red-colored pebbles on the other appears to be based on the mineralogic character of the limonite. The red color appears to indicate weathering conditions quite different from those indicated by buff and brown colors. This difference is probably similar to that which, today, causes a piece of the same steel to form a light-brown rust in northern United States and a reddish-brown rust in the tropics.

Some of the pebbles, such as are illustrated in Figure 9 (p. 31), have two or more zones of weathering. If one assumes that the weathering progressed inward from the surface of the pebble and that successive processes of weathering, differing in type and in time, operated on the pebble, then the successive zones may be taken as a record of the weathering history of the pebble. Thus, there are four separate zones of weathering in pebbles taken from Illinoian deposits. There is:

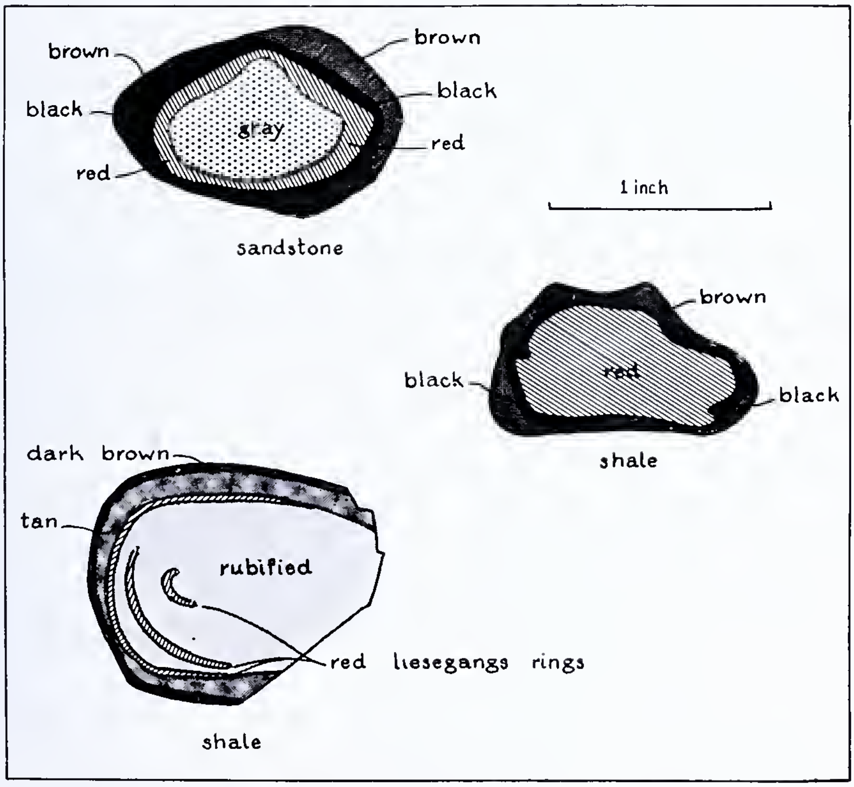

FIGURE 9. Diagrams of weathered pebbles from Illinoian glacial gravel deposits.

(1) at the surface a tan-colored zone; beneath it (2) a dark-brown zone; then, (3) a brick-red or pink zone; and finally (4) a buff-colored zone of slight alteration overlying unaltered rock. It is assumed that limonite has been leached from the outer, tan-colored zone and concentrated in the inner, dark-brown zone. The brick-red or pink zone is characteristic and, as no such red zone is found in Wisconsin pebbles, this zone is assumed to be a product of post-Illinoian, pre-Wisconsin weathering. The sequence of zones in the Illinoian pebbles is taken to represent: (1) a period of slight oxidation and leaching, followed by (2) severe oxidation and reddening in pre-Wisconsin time, and (3) a period of less severe oxidation in post-Wisconsin time. Wisconsin pebbles commonly show only three zones: an inner buff one (4) of slight oxidation; and an outer pair representing slightly more severe oxidation (2) and attendant leaching (1) near the surface.

The history of soil development on the glacial deposits was similar to that of the weathering of the separate pebbles, for the Illinoian deposits are characterized by a lower, tan, oxidized horizon overlain by a red horizon, above which there is a brown to buff post-Wisconsin soil. Such a deposit is well shown at Penny Hill (m.145) on the West Branch and will be discussed in detail on page 44. The Wisconsin deposits are characterized by a lower, tan, oxidized horizon overlain by a brown to buff, post-Wisconsin soil. No red soil horizon was developed in any Wisconsin deposit. However, the depth of soil development, particularly the thickness of the B-horizon and the depth of oxidation, differ sharply, as is shown in Figure 10 (p. 37), not only between Illinoian and Wisconsin deposits, but between the deposits of different sub-stages within the Wisconsin. The difference in the weathering of the soils, between those developed on Illinoian glacial deposits and those on Wisconsin deposits, was noted by Leverett (1934) and his descriptions are here confirmed and extended. The soils developed on Illinoian deposits and in the periglacial region are similar to those in New Jersey described by MacClintock (1940), in that they have both podsolic and lateritic properties. MacClintock pointed out that the lateritic character of these soils was probably inherited from the last warm, humid, interglacial climate, and that the podsolic character was produced under a later, cooler climate.

Beyond the limits of glaciation the weathering of the pebbles and the development of soil zones are similar to those of the glaciated area. Some deposits are similar in these respects to Illinoian glacial deposits, and one may assume that they were laid down at corresponding times. In addition to these there are a few deposits (page 46) which are clearly older than the Illinoian. They are reddish-brown in color, but show signs of a more severe leaching. The red color is not as deep as in the Illinoian deposits and is frequently mottled with gray.

WEATHERING OF PEBBLES

Granitic Pebbles.

A statistical analysis of the weathering of pebbles of granite and gneiss, such as was used by MacClintock (1940) in determining a division of the Jerseyan deposits in New Jersey, could not be made in the Susquehanna Valley for, as is shown in Tables 3 and 6 (pp. 18, 20), such pebbles are relatively scarce. However, pebbles of granite and gneiss found in the Illinoian deposits have a mean weathering, following MacClintock's method, of about 70 per cent, and those found in the Olean deposits about 40 per cent. Many of the granitic pebbles must have been weathered before deposition, for those found in unoxidized and unleached horizons show a mean weathering of about 20 per cent. The granites weather chiefly by the alteration of their feldspars, which become chalky in appearance and eventually crumble and disappear. Alteration of iron minerals to limonite gives the rock a tan or buff color. The pebbles usually retain their shape throughout the alteration, held together by a skeleton of quartz grains. The granites of the Wisconsin and Illinoian deposits show no apparent difference in type of weathering. The weathering of Illinoian pebbles is, however, more nearly complete.

Quartzite.

In the Illinoian deposits white quartzite pebbles are weathered to a tan color; those of pink quartzite are surrounded by a thin, light-colored surface shell as though bleached.

Conglomerate.

The conglomerate, when fresh, is steel-gray, medium- to fine-grained, arkosic conglomerate composed of rounded quartz pebbles and mica flakes in a gray ground mass. When found as a pebble in a gravel deposit, it is either thoroughly weathered or fresh. In the Wisconsin deposits the conglomerate pebbles have light-brown specks scattered throughout the ground mass, and light-brown stains on the quartz pebbles and along the joint planes. In the Illinoian deposits some of the pebbles may have a slightly pink color and others a brown color.

Sandstone.

Three lithologically different sandstones occur in the glacial deposits. In their unweathered form they are: (1) a medum-grained, white sandstone; (2) a coarse- to fine-grained, gray or greenish-gray, arkosic sandstone; and (3) a fine-grained, micaceous, red or purplish-red sandstone. The white sandstone, when found in Wisconsin deposits, is frequently surrounded by an oxidized, buff-colored shell about ⅛ inch thick. One white sandstone pebble found in a Binghamton outwash deposit at Selinsgrove contained a red oxidized zone which was truncated by the surface of the pebble. This is taken to indicate that this pebble was weathered during the pre-Wisconsin interglacial period, transported and redeposited during the Binghamton sub-stage. Such pebbles are not uncommon outside of the Olean ice limits, or near the ice limit within the area covered by Olean ice. In the Illinoian deposits the white sandstone pebbles commonly have an outer, yellowish-brown shell ⅛ inch thick, and below that a darker-brown or reddish-brown zone ¼ to ½ inch thick.

The gray sandstone, upon weathering, breaks down into a friable material by the selective weathering of iron-bearing minerals in the rock. Pebbles found in Binghamton deposits are only slightly altered, have a buff color and a very thin, light-brown shell on the surface. Pebbles in the Olean deposits have a deep shell of a yellowish-brown or buff color and, at the surface, there is often a dark-brown shell ⅛ to $\frac{1}{16}$ inch thick. Pebbles of the same rock in Illinoian deposits are usually so deeply weathered as to be crumbly. The outside is usually a dark-brown or black shell as much as ½ inch thick. Beneath this the rock is buff- or tan-colored. Occasional pebbles may show a third zone of grayish-pink color near the base of the dark-brown shell or in the center of the pebble.

Red sandstone, because of its inherently deep color, does not reveal the degree of weathering as readily as do the other sandstones. In both the Binghamton and Olean deposits the surface of the red sandstone pebbles is usually marked by a thin, yellowish-brown to light-brown shell which, in the Olean deposits, may reach ¼ inch in thickness. Beneath this there is often a zone in which the pebble has changed from its former purplish-red color to a lighter shade and contains bright red specks.

Siltstone.

No sharp distinction separates the fine-grained, gray sandstone from the gray siltstone, nor the red sandstone from the red siltstone. The siltstones are finer-grained and have a more highly developed platy cleavage than is generally true of the sandstones; however, they are similar in mineral composition. In the Olean deposits the gray siltstones appear to be weathered by the penetration of a light-brown limonite stain which tends to concentrate first along the cleavage planes and then to completely penetrate the rock. These completely limonitized pebbles are usually surrounded by a shell, $\frac{1}{16}$ inch thick, of a darker-brown color. The red siltstone pebbles found in the Olean deposits are altered, from the surface inward, to a light, yellowish-brown or buff color in contrast to their original purplish-red color. The weathering features of pebbles of siltstone were not distinguished from those of sandstone pebbles in the Illinoian deposits.

Calcareous Siltstone.

Weathered "ghosts" of what were probably once pebbles of calcareous siltstone occur scattered throughout the leached horizons of the Wisconsin deposits. They have the outward appearance of pebbles, but may be reduced to a dark-brown dust between the fingers. These "ghosts" were formed by solution of the calcareous part of the pebbles, and they now are held together by a skeleton of silt or sand grains.

Shale.

Three types of shale occur in the Pleistocene deposits: (1) a black shale, (2) a blue-green or olive-green to gray shale, and (3) a red shale. The red shale, which appears to have been derived mostly from the Silurian Bloomsburg and Mississippian Mauch Chunk formations, shows little change as a result of weathering. The alteration is in the form of a bleaching of the surface and is the same in both Wisconsin and Illinoian deposits.

The blue-green shale, derived chiefly from the Lower Silurian formations, contains enough iron to be a sensitive indicator of changes in weathering. Pebbles of this type, found in Illinoian gravel deposits (fig. 9, p. 31), commonly have a brick-red zone in the interior, in which the red color is concentrated along the cleavage planes. This is surrounded by a dark-brown shell 1/16 inch thick and, on the surface, by a light-brown crust of similar thickness.

Chert.

Chert pebbles of black, light-gray, buff or white color occur throughout most of the glacial and periglacial gravel deposits. They do not appear to reveal anything concerning the history of weathering. However, the patina which develops by the weathering of the chert is porous and admits iron-bearing ground waters. Some of this iron must have been deposited as limonite for, in both Wisconsin and Illinoian deposits, chert pebbles are found whose outer 1/16 to 1/8 inch of patina has been stained to a buff color. In addition, occasional chert pebbles may be found, in the Illinoian gravels, in which the patina has a pink color.

Summary.

The development of a red weathering zone in the pebbles is common only in the pre-Wisconsin deposits. Weathered pebbles found in the Wisconsin deposits, as, for example, in the kame gravels near the "terminal moraine", occur also below the depth of leaching and oxidation of the deposit; and it must be assumed that they were eroded and transported by the ice after they had become weathered. On the other hand, the pebbles in the Wisconsin, and particularly the oldest Wisconsin or Olean deposits, are generally weathered only to a brown color. This brown zone is also present in pebbles in the deposits of Illinoian age. One must, therefore, conclude that the development of the red zone occurred during pre-Olean time and that some, at least, of the brown zone is the product of post-Wisconsin weathering. The brown zone may, however, be the product of a somewhat cooler climate in the mountainous parts of the area during the pre-Wisconsin interglacial period, and be contemporaneous with the development of the red color at lower elevation in the valleys of the area.

SOILS

General Statement.

The weathering history of the soils of the Susquehanna Valley is reflected in their structure and physical properties. The length of time during which weathering was active is reflected in the depth of development of the soil. The kind of climate which prevailed during weathering is reflected in the type of soil which was produced. The climatic history of the Susquehanna Valley is assumed to have been the same throughout the area included in this report, except that the tops of the mountains were, at all times, cooler than the floor of the valley. Thus, the climatic history of all deposits of the same age must have been the same. One may, therefore, correlate deposits of the same age by means of the evidence provided by their soils.

Both monogenetic and polygenetic soils, as defined by Bryan and Albritton (1943), occur within the Valley. Simple, monogenetic soils occur on the gently sloping, gravel terraces of Binghamton or younger age. Polygenetic soils, produced by surficial deposits of loess, occur on some of the Olean terraces. The still older terraces have polygenetic soils or display fossil soils buried beneath younger deposits. The pre-Olean (pre-Wisconsin) soils, as will be shown on page 43, are red or reddish-brown in color; those of Olean age or younger are brown. Obviously the soils which prevailed in this region before Olean time were different from those since developed.

Previous studies of the soils in the Susquehanna Valley by Shaw, Byers and Ross (1912); Wood, McKee, Skemp, Nissley and Dickey (1913); Shaw, McKee and Ross (1914, 1915); Gilbert, Cobb, Moffitt and Cox (1916); Stevens, Hendrickson, Manifold, Degan and Patrick (1923); Hendrickson, Burke, Goodman and Smith (1929); Bonsteel and Bass (1940); Higbee, Bacon, Burke, Patrick, Brown, Tedrow, Long and Atkinson (1944); and others, have emphasized the lithology of the parent material and the distribution of size-grades in the soil. The age of the soil is, therefore, not brought out by these studies except where differences in the geologic history led to differences in the grain size or lithology.

The earliest soil studies classified the terrace soils into: (1) those found on the first bottom or on slightly higher terraces; (2) those derived from glacial outwash including mixtures of glacial and periglacial alluvium, and also periglacial alluvium; and (3) those of red and gray color. The relationship of these soils to each other is shown in Table 12 (p. 36). More recent studies have led to a further division of these soil series on the basis of finer distinctions between the parent materials. Still more critical subdivision is possible. The soil series, as they have so far been identified, may be further studied, and subdivided according to the length of time the soils have been exposed to weathering.

TABLE 12. *Terrace Soils in the Susquehanna Valley after Shaw, Byers and Ross (1912); and Shaw, McKee and Ross (1914, 1915).*

TERRACE	COLOR	PARENT MATERIAL		
		glacial outwash	mixed outwash & periglacial gravel	"non-glacial" or periglacial sand & gravel
high terraces	gray	Chenango	Wheeling	Holston
low terraces	gray	Genesee	Huntington	
	red	Barbour	Moshannon	

As explained on page 13, each terrace is of a different age. The age of each terrace, and, therefore, the maximum length of time which the surface of the terrace has been exposed to soil-forming processes, varies directly with its height. The "high" terrace soils, such as the Chenango, Wheeling and Holston series shown in Table 12 (p. 36), occur at elevations between 40 and 100 feet above the river and are Pleistocene, whereas the low terrace soils such as the Genesee, Barbour, Huntington and Moshannon series are within the present flood level and are continually renewed by flood-deposited silt.

Gilbert, Cobb, Moffitt and Cox (1916) mapped the Elk fine sandy loam, Elk gravelly loam, and the Elk silt loam near Marietta (m.44). These classes of the Elk series, defined as soils developed from old deposits of alluvial soil materials, appear to correlate with the Middle Wisconsin (Binghamton ?), Olean and Late Illinoian terraces respectively. Similar divisions were recognized by Higbee, Bacon, Burke, Patrick, Brown, Tedrow, Long and Atkinson (1944), who distinguished

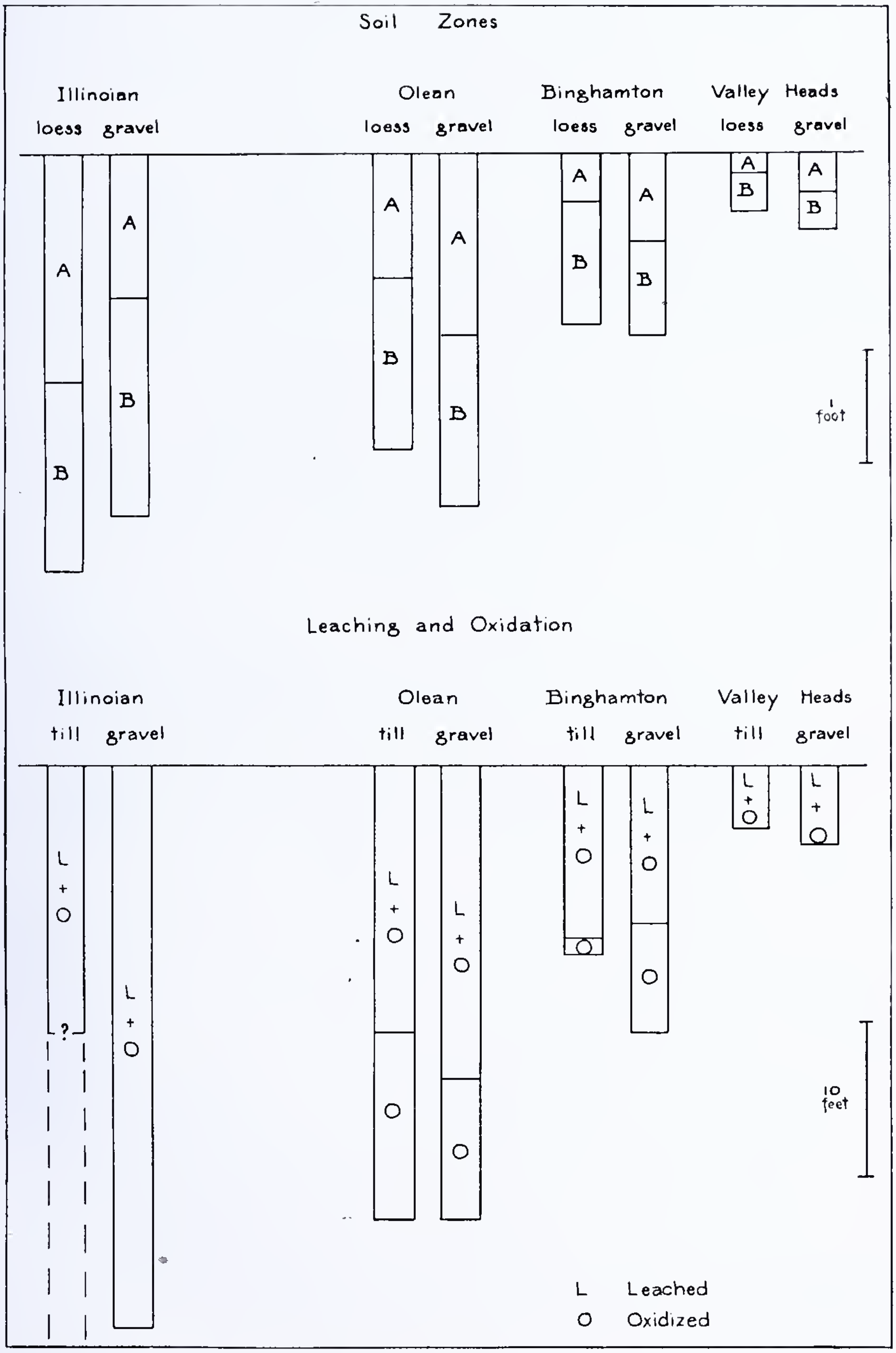

FIGURE 10. Graphic comparison of depth of soil development and chemical change in Illinoian and Wisconsin glacial deposits.

high-bottom phases of the Huntington, Moshannon, Pope and other soil series, which lie on the Olean-to-Recent composite terrace near Mapleton (m.166), described on page 124. They also distinguished a high-terrace phase of the Holston silt loam, 100 to 250 feet above the present stream level, which may be an attempt to explain the differences between the soils developed on the pre-Illinoian terraces and those found on the younger terraces.

Similar distinctions, based on the duration of weathering, may be made within the non-alluvial soil series. It is possible to divide the Volusia soils into those developed upon deposits of blue-gray till of the Binghamton glacial sub-stage and those developed on similar till of the Olean glacial sub-stage. The lithologic difference between these two tills, as shown in Table 3 (p. 18), is not great, but there is a major difference, as shown in Figure 10 (p. 37), in the depth of soil development, oxidation and leaching. Some of the Dekalb, Gilpin, and other soils which are developed upon congeliturbate deposits in the periglacial region could also be divided into soils of different ages, as is shown by weathering differences discussed on pages 59 to 64.

Soils in the Glaciated Region.

Two kinds of soil may be recognized in the Susquehanna Basin: one developed upon till or outwash; and the other upon the gravel, rubble, or wind-borne deposits of the periglacial region. The soils developed on glacial deposits have a known maximum age. The age of the soils in the periglacial area must be inferred by a comparison of their characteristics with those developed on actually dated material. Soils of six different ages are recognized: Recent or Modern, post-Valley Heads, post-Binghamton, post-Olean, post-Illinoian and pre-Illinoian.

Recent soils are represented by the alluvial deposits of modern floods. On the West Branch of the Susquehanna River the deposits are predominantly silt with a clay component. These soils may be recognized as Recent in origin because the clay has not been carried down into the subsoil, but remains near the surface. The Recent, silty soils are heavier at the surface than are older soils of similar origin, and there is no significant development of eluvial A, and illuvial B, horizons. On the North Branch of the Susquehanna, and on the main stream the flood deposits contain medium- to fine-grained sand as well as silt. Below the junction with the Lackawanna River these deposits are easily recognized, for they are black with culm.

The post-Valley Heads soils are known from a few exposures on the North Branch near its junction with the Chemung River. Here the outwash deposits of Valley Heads age are leached of calcium carbonate to a depth of 5 feet and oxidized to the same depth. Soil zones are poorly developed on these deposits and generally do not extend below 8 to 10 inches, as shown in Table 13 (p. 39). On a gravel terrace, one mile south of Hornbrook (m.269), there is a soil developed directly upon medium-grained, well sorted, calcareous outwash gravel of Valley Heads age. There is no silt lying upon the terrace at this place, and the soil is poorly developed. The A-horizon is 4 inches thick and the B-horizon 4 inches thick. The two soil horizons and the underlying gravel are leached of calcium carbonate to a depth of 5 feet.

TABLE 13. *Geologic Section in Gravel Pit, 1 mile south of Hornbrook, Towanda, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Gravel, *Valley Heads,* gray, medium-grained, sandy, loose, leached, oxidized	0	4
2.	Gravel, *Valley Heads,* buff, medium-grained, contains silt and sand, slightly more compact, leached, oxidized	0	5
3.	Gravel, *Valley Heads,* buff, medium-grained, well sorted, contains lenses of sand and silt, leached, oxidized	4	3
4.	Gravel, *Valley Heads,* gray, medium-grained, well sorted, calcareous, unoxidized. To base	3	0
	Total	8	0

Depth of leaching: 5 feet
Depth of oxidation: 5 feet

The soils on the Binghamton deposits show a slightly greater degree of development (fig. 10, p. 37). They are leached of calcium carbonate to a depth of about 11 feet and oxidized to a depth of 12 feet. Soil zones found on Binghamton gravels are generally about 19 inches thick and consist of an eluvial horizon of 8 inches underlain by an illuvial horizon of 10 inches. Such a soil is exposed in a gravel pit in a terrace 36 feet above the Susquehanna River, ½ mile south of Forty Fort (m.186). Here, as is described in Table 14 (p. 39), there is a surface deposit, 9½ inches thick, of medium-grained gravel in a gray, silty matrix, underlain by a similar gravel, 10 inches thick, embedded in a matrix of buff sand which contains enough silt to cause it to compact slightly. Leaching has extended to a depth of 11 feet and oxidation to a slightly greater depth. The oxidized zone, like the A- and B-horizons, is not well developed and its base is not sharply defined. Other post-Binghamton soils are found associated with Olean deposits and are described below in connection with them.

TABLE 14. *Geologic Section in Gravel Pit, ½ Mile South of Forty Fort (m.186), Pittston, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Gravel, *Binghamton,* light gray, silty, medium-grained, leached, oxidized	0	9½
2.	Gravel, *Binghamton,* buff, sandy, medium-grained, slightly compact, leached, oxidized	0	10
3.	Gravel, *Binghamton,* tan, sandy, medium-grained, leached, slightly oxidized	9	4
4.	Gravel, *Binghamton,* brownish-gray, sandy, medium-grained in medium-grained sand matrix, calcareous, slightly oxidized	7	0
5.	Conglomerate, *Binghamton,* gray, sandy, medium-grained, unoxidized; cemented with calcite. Exposed	5	0
	Total	22	11½

Depth of leaching: 10 feet
Depth of oxidation: not distinct, 10 to 18 feet

The Olean deposits (fig. 10, p. 37) are generally leached to depths of 15 to 20 feet and oxidized for at least 20 feet. The A-horizon is about 15 inches thick and the B-horizon about 18 inches thick. A soil developed upon a loess and the Mohawk Valley type of Olean outwash is exposed in a pit two miles west of Falls (m. 205), as shown in Table 15 (p. 40) and Figure 11 (p. 40). This soil was identified by Hendrick-

TABLE 15. *Geologic Section in Gravel Pit, 2 Miles West of Falls (m.204), Pittston, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Loess, *Olean*, buff, loose, pebbly, leached, oxidized	1	1
2.	Loess, *Olean*, light brown, compact, pebbly, leached, oxidized	1	4
	——*unconformity*——		
3.	Sand, *Olean*, light brown, medium-grained, silty, leached, oxidized	1	8
4.	Sand, *Olean*, tan, medium-grained, leached, oxidized; contains silt lenses	10	0
5.	Sand, *Olean*, light gray, medium-grained, unoxidized, calcareous; contains silt lenses	6	0
6.	Gravel, *Olean*, light gray, medium to coarse-grained, unoxidized, calcareous; contains scattered boulders; to base	10	0
	Total	30	1

Depth of leaching: 14 feet
Depth of oxidation: 14 feet

son and others (1929) as Chenango gravelly loam. At this exposure a 2-foot deposit of pebbly loess lies unconformably on a 10- to 15-foot layer of medium-grained sand with horizontal silt lenses. A deposit of medium- to coarse-grained gravel, 10 feet thick, is exposed beneath the sand. The A-horizon is 13 inches thick and the B-horizon about 24 inches thick. Leaching extends to a depth of 12 feet. This degree of soil development appears to be in accord with an Olean age for the loess and a post-Olean age for the soil. There is no evidence of superposition of successive periods of soil development and no significant interval of time is presumed to have elapsed between the deposition of the outwash and the deposition of the loess. Further discussion of the pebbly loess and the underlying unconformity is given on page 54.

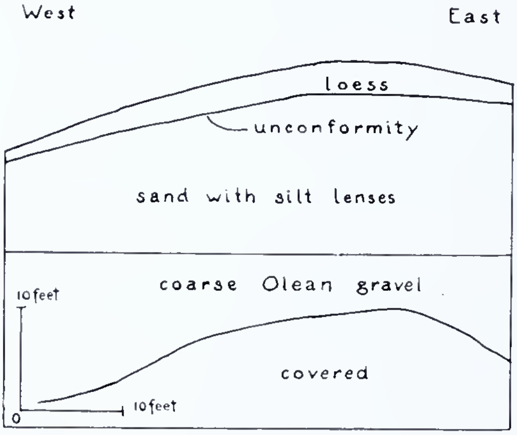

FIGURE 11. Relationship of materials exposed in gravel pit (m.205) near Falls.

A soil (Table 16, p. 41), previously identified by Hendrickson and others (1929) as Wooster gravelly silt loam, is exposed in the right bank of Tunkhannock Creek just south of East Lemon. It is developed upon an Olean outwash derived from the Hudson Valley ice. The A-horizon is 19 inches thick and is clearly divisible, here, into four parts: an upper layer, 2 inches thick, of yellowish-white silt; a 4-inch layer of light-gray, very powdery, fine silt; a 4-inch layer of buff-colored, friable silt which will compact and slick between the fingers; and a 9-inch layer of fine-grained gravel in a buff-colored, loose, silt matrix.

TABLE 16. *Geologic Section on Right Bank of Tunkhannock Creek at East Lemon, Tunkhannock, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Loess, *Binghamton* (?), yellowish-white, loose, non-calcareous, oxidized	0	2
2.	Loess, *Binghamton* (?), light gray, very powdery, non-calcareous, oxidized	0	4
3.	Loess, *Olean* (?), buff, loose, friable, will compact, non-calcareous, oxidized	0	4
4.	Gravel, *Olean*, buff, loose, silty, fine-grained, non-calcareous, oxidized	0	9
5.	Gravel, *Olean*, buff, compact, silty, medium-grained, non-calcareous, oxidized	0	6
6.	Gravel, *Olean*, mottled gray and brown, compact, jointed, sandy, medium-grained, non-calcareous, oxidized	1	0
7.	Gravel, *Olean*, buff, sandy, medium- to coarse-grained, non-calcareous, oxidized	6	0
8.	Silt, *Olean*, buff, pebble-free, non-calcareous, oxidized; witb bands of dark brown, clayey silt	4 to 5	0
9.	Sand, *Olean*, buff, very fine-grained, non-calcareous, oxidized. Exposed	18	0
10.	Covered to creek	10	0
	Total	41 to 42	1

Depth of leaching: at least 32 feet
Depth of oxidation: at least 32 feet

The B-horizon is 18 inches thick and is divisible into an upper layer, 6 inches thick, of medium-grained gravel in a buff-colored, compact, silt matrix; and a lower layer, 12 inches thick, of similar gravel in a mottled gray and brown, compact, jointed, medium-grained sand. This is a polygenetic soil as defined by Bryan and Albritton (1943), the result of more than one cycle of soil development, for the yellowish-white silt at the surface has not been as thoroughly leached of its iron as has the layer immediately below it; and the layer of buff-colored silt, 6 to 10 inches below the surface, has some of the characteristics of an illuvial zone when compared to the deposits above it. Part of the surface layer may be Binghamton in age and distinctly younger than the rest of the deposit and may have been laid down by the wind after the post-Olean soil had been podsolized. The buff silt, 6 inches below the surface, may, then, represent the newly developing B-horizon. This hypothesis implies the existence of two soils: one with an A-horizon of 17 inches and a B-horizon of 18 inches; and another, superimposed upon it, with an A-horizon of 6 inches and a B-horizon of 13 inches. In the terminology of Bryan and Albritton (1943) this soil is both complex and composite. The younger soil is comparable, in development, to that found on the Binghamton deposits and it is supposed that the loess was deposited during the Binghamton sub-stage.

Another composite soil, previously discussed on page 22 and shown in Table 9 (p. 23), is exposed in a road cut and gravel pit on Highway 309, just north of Luzerne (m.186). Here there is a 3-foot layer of loess. In this loess the upper A-horizon is 5 inches thick and the B-horizon is 13 inches thick. The A-horizon consists of a 1-inch zone of black, silty loam underlain by 4 inches of loose, dark-brown, pebbly silt. The B-horizon consists of a 3-inch layer of slightly more compact, light-brown, pebbly silt underlain by 10 inches of light-brown, compact, silty sand. The soil horizons closely resemble, in thickness, those of the younger soil of supposed post-Binghamton age at East Lemon and the soil on the Binghamton gravel terrace at Forty Fort; and one is led to suppose that it represents post-Binghamton weathering on a loess which was deposited during the Binghamton sub-stage.

The sediments deposited in a terrace 15 feet above Sugar Creek at the bridge of Highway 6, 2 miles east of Luthers Mills, contain a soil profile which also appears to be composite and polygenetic rather than simple in origin. The soil, as is shown in Table 17 (p. 42), consists of a surface layer, 8 inches thick, of loose, gray, gravelly silt, underlain by two brown, silty layers 9½ inches thick in all, which appear to contain both silt and iron carried down from the surface layer. The upper 8-inch layer is the present A-horizon and the two silty layers are, together, the B-horizon. However, at a depth of 25 to 49 inches there is a lighter-colored, yellowish-brown silt which appears to have been once partly podsolized and the iron, derived from it, deposited in an orange-brown feretto zone 80 to 92 inches below the present surface.

TABLE 17. *Geologic Section on the Left Bank of Sugar Creek, 100 Yards East of Bridge of U. S. Highway 6, 2 Miles East of Luthers Mills, Sayre, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Silt, *Binghamton* (?), gray, friable, gravelly, leached, oxidized	0	8
2.	Silt, *Binghamton* (?), brown, slightly compact, gravelly, leached, oxidized	0	5
3.	Sand, *Binghamton* (?), brown, slightly compact, silty, leached, oxidized	0	4½
4.	Gravel, *Binghamton* (?), light brown, loose, fine-grained, leached, oxidized	0	7
5.	Silt, *Olean*, yellowish-brown, pebble-free, leached, oxidized (podsolized zone)	1	0
6.	Gravel, *Olean*, yellowish-brown, fine-grained, silty, leached, oxidized; lenticular	0 to 1	0
7.	Sand, *Olean*, brown, compact, jointed, fine-grained, leached, oxidized .	2	7
8.	Sand and gravel, *Olean*, reddish-brown to orange-brown, limonite cemented, leached, oxidized (feretto zone)	1	0
9.	Gravel, *Olean*, brown, very coarse, bouldery, leached, oxidized	3	11
10.	Sand, *Olean*, brown, clayey, medium-grained, leached, oxidized	0	6
11.	Sand, *Olean*, blue-gray, clayey, medium-grained, calcareous, unoxidized	0	10
12.	Clay, *Olean*, blue-gray, silty, calcareous, unoxidized. Exposed to creek	0	15
	Total	14	1½

Depth of leaching: 12 feet
Depth of oxidation: 12 feet

This silt appears to be the top of the Olean deposits and to have a soil profile of post-Olean, pre-Binghamton age. The present soil resembles, in its degree of development, other soils supposed to have formed since the Binghamton sub-stage. The greater part of the material exposed, however, was laid down during the Olean sub-stage, for it consists of the deposits of an Olean ice-front lake and outwash deposits from a body of ice which stood at the mouth of Sugar Creek (m.267) and which deposited the till described on page 57. No Binghamton outwash has been found in this valley. It is, therefore, likely that the ice-front lake deposits, represented by the lower 15 inches in the column shown in Table 17, (p. 42), were followed in turn by the deposition of 137 inches of material which consists of both glacial outwash and deposits of periglacial origin in Olean time, and that the upper 17 inches represents a deposit of periglacial origin of approximately Binghamton age. Leaching and oxidation have extended nearly to the level of Sugar Creek and are not as great as are commonly found in Olean deposits. One is led to suppose that the ground water table, represented by Sugar Creek, acted as a lower limit to these soil-forming processes and that, therefore, the depth of leaching and oxidation does not, here, indicate the age of the deposits.

TABLE 18. *Geologic Section in Gravel Pit on Highway 404, 1¼ Miles North of New Columbia (m.136), Milton, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loess, *Olean* (?), gray, loose, friable, pebble-free; probably disturbed by cultivation	0	11
2.	Loess, *Olean* (?), buff, crumbly, pebble-free, with horizontal joint system	1	5
3.	Sand, *Illinoian*, mottled gray and rusty-brown, very fine-grained	1	3
4.	Sand, *Illinoian*, brown, compact, jointed, pebbly; with scattered, small, open voids; black stain on some joint planes; becomes reddish-brown with yellowish-brown on joint planes in lower 4 inches	1	11
5.	Gravel, *Illinoian*, brick-red, compact, fine-grained; in a matrix of fine sand with clay; with scattered, small, open voids	1	9
6.	Gravel, *Illinoian*, brick-red, loose, fine-grained; with open voids; in a matrix of medium-grained sand. Exposed	2	10
7.	Covered	3	0
	Total	13	1

Non-calcareous
Depth of oxidation: at least 10 feet

The Illinoian deposits are weathered much more deeply than those of Wisconsin age. However, in most instances, the pre-Wisconsin soil was stripped from the slopes by congeliturbation during the Wisconsin glacial substages, as is described on page 28. The A-horizon of the pre-Wisconsin soil is nearly everywhere gone, and post-Wisconsin soils have developed as complex soils upon the remnants of the older pre-Wisconsin soils. As a result, the soil zones found on Illinoian deposits are similar to those found on deposits of Olean age, as is shown in Figure 10 (p. 37). The nature of the pre-Wisconsin weathering was different in that a reddish, rather than a brown, sub-soil was developed. This relationship, as explained on page 31, is thought to be due to slightly different conditions of weathering of the iron compounds and to indicate the presence of a slightly warmer climate in this region than has existed here since the Wisconsin glaciations. Such a soil has developed on the Illinoian gravel terrace, and is exposed in a gravel pit (Table 18, p. 43), 1¼ miles north of New Columbia (m.136). At the surface there is an 11-inch layer of loose, pebble-free, gray silt which has probably been disturbed by cultivation. Below it there is a 17-inch layer of buff, pebble-free silt with a horizontal joint system. It is a loess, probably deposited in Olean time. Below the silt, lie Illinoian beds which begin with two rusty-brown layers. The upper layer, 15 inches thick, is composed of mottled-gray and rusty-brown, very fine sand; and the lower layer, 23 inches thick, is composed of compact, jointed, brown, pebbly sand which grades downward into a reddish-brown deposit toward its base. The two lowest layers in the pit are red in color. The upper layer, 21 inches thick, is composed of compact, red, fine-grained gravel in a matrix of fine sand and clay. The lower layer, of which 34 inches is exposed, is composed of brick-red, fine-grained gravel in a matrix of medium sand. There is insufficient evidence at hand to indicate whether the rusty-brown layers represent the eluvial zone developed at the same time as the red layers, or whether they represent a different period of weathering which intervened between the development of the red colors of the lower horizon and the periglacial conditions of the Olean sub-stage. In either case the "weathering products" in the Illinoian deposits must have been produced by soil-making processes which prevailed during the pre-Wisconsin interglacial interval, but have not prevailed, here, since that time. The distinct difference between the weathering of the Illinoian deposits, here described, and the Wisconsin deposits, described on pages 38 to 42, makes such an assumption imperative.

The weathered till exposed in the western end of the road cut 1¼ miles northwest of Selinsgrove (m.115), illustrated in Figure 7 and previously discussed on page 28, is divisible into five zones (Table 19, p. 44), of which the upper probably represents the post-Wisconsin modification of the remnants of a pre-Wisconsin soil. At the surface there is a 3-inch zone of buff-colored, silty loam. It is underlain by a 5-inch zone of brick-red, silty till which contains more clay than the surface zone. Below this the sequence is repeated, for there is first a 9-inch zone of buff-colored, jointed, silty till and then a 36-inch zone of compact, brick-red, clayey till. This is underlain by about 63 inches of yellowish, silty till which is mottled with brick-red. In places this yellowish till is separated from the overlying red till by a brown, rusty zone, 2 to 3 inches thick. At the base of the yellowish till there is a body of gray and buff residual clay which contains some foreign pebbles from the over-lying till. The lower buff and red till layers contain more clay than the similar upper layers, but are otherwise the same. They may be portions of the same soil horizon which have been repeated by overriding as soil material slid down the slope, as was previously postulated for this hill (p. 30). The difference in clay content, between the upper and lower brick-red zones, is interpreted to be the result of soil-forming processes which were active after the surface deposits reached their present position. Thereby, the clay, which the upper brick-red zone is supposed once to have had, was carried deeper into the ground by downward-percolating ground waters. The weathering of the buff-colored soil at the surface resembles that found on Wisconsin deposits and is probably a product of post-Wisconsin conditions.

TABLE 19. *Geologic Section in Road Cut on U. S. Highway 522, 1¼ Miles Northwest of Selinsgrove (m.115), Sunbury, Pa., Quadrangle. Section 250 Feet from Western End of Cut.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Congeliturbate, *Wisconsin* (?)		
a.	Till, *Illinoian*, buff, silty, pebbly, non-calcareous, oxidized	0	3
b.	Till, *Illinoian*, brick-red, jointed, silty, clayey, non-calcareous, oxidized	0	5
2.	Till, *Illinoian*, buff, jointed, silty, pebbly, non-calcareous, oxidized	0	9
3.	Till, *Illinoian*, brick-red to terra-cotta, compact, clayey, pebbly, non-calcareous, oxidized; irregular base	3	0
4.	Till, *Illinoian*, yellowish-brown, mottled with red spots along joints, compact, silty, pebbly, non-calcareous, oxidized; in places separated from horizon 3 by a brown, rusty zone, 2 to 3 inches thick; irregular base	7	0
5.	Clay, *post-Illinoian*, gray and buff, pebbly, non-calcareous; a residual clay produced by weathering of the underlying shale; contains pebbles from the overlying till. Exposed	0	6
	Total	11	11

Depth of leaching: at least 11 feet
Depth of oxidation: at least 11 feet

The zones of weathering, described for the Illinoian till deposits, are also evident in the weathering of the bedrock, illustrated in

Figure 8 (p. 29). Here, most of the Illinoian till is gone from the rock surface and the rock has developed an upper, red-stained zone and a lower, brown-stained zone whose thicknesses are slightly greater than those in the adjacent till, as shown in Figure 8 (p. 29). These weathering zones are the result of peculiar weathering conditions of post-Illinoian time which attacked all types of materials. However, the effect of these peculiar conditions is more striking in materials such as till, shale and siltstone, than in others, such as quartzite and limestone.

Soils in the Periglacial Region.

There is no difference in the thickness or the type of weathering of the soils in the glaciated region from those of the periglacial region nearby. The soils differ only because of differences in parent material. Unless the soil is composed of a gravel or rubble which was deposited during the Wisconsin time, it is likely to be complex and show the effects of both pre-Wisconsin and post-Wisconsin weathering. Along the south flank of Blue Mountain (m.74), east of the Susquehanna River, the rubble derived from the Tuscarora sandstone and Shawangunk conglomerate is characteristically weathered to a soil composed of four zones. The surface layer is black, organic matter mixed with sand 1 to 2 inches thick. Below this there is usually a medium-grained, white sand layer about 2 inches thick. This is underlain by 6 inches of loose, crumbly, buff-colored silt making a total A-horizon of 9 inches. This complex A-horizon is underlain by a dark-brown to reddish-brown, clayey silt which appears to have been weathered during pre-Wisconsin time and to again be undergoing weathering. It represents the B-horizon of the upper 9-inch soil but its reddish-brown color is retained from pre-Wisconsin time. The A-horizon is thick but undeveloped and is probably of post-Wisconsin age.

Polygenetic soils which show traces of pre-Wisconsin weathering are common throughout the periglacial region. In an abandoned gravel pit on Highway 441, 1 mile west of Marietta (m.44), there is exposed a soil which Gilbert and others (1916) identified as Elk silt loam. It consists of: a surface layer, 4 inches thick, of gray, silty loam; underlain by 48 inches of reddish-brown, pebbly silt; and 30 inches of yellowish-brown, pebbly silt, (see Table 20, p. 45). The occurrence of a red zone overlying a yellow zone is similar to that found in the

TABLE 20. *Geologic Section in Abandoned Gravel Pit on Highway 441, 1 Mile West of Marietta (m.46), Middletown, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Silt, *Illinoian*, gray, pebbly	0	4
2.	Silt, *Illinoian*, reddish-brown, pebbly	4	0
3.	Silt, *Illinoian*, yellowish-brown, pebbly in places; possibly loess	2	6
4.	Gravel, *Illinoian*, brown, medium-grained, cemented with sand and black limonite or manganese	2	0
5.	Gravel, *Illinoian*, brown, medium-grained	1	0
6.	Covered	8	0
7.	Limestone, Ordovician, gray, fine-grained. Exposed	1	0
	Total	18	10

Depth of leaching: about 17 feet
Deptb of oxidation: about 17 feet

Illinoian till at Selinsgrove and Penny Hill, described on pages 44 and 28. The gray surface layer is probably a podsolized soil of Wisconsin age. A similar soil is developed on gravel exposed in a pit about ½ mile south of Thompsontown (m.108) on the Juniata River. Here, as shown in Table 21 (p. 46), there is, at the surface, a 1-inch layer of gray loam containing decayed plant debris, underlain by a layer, 4 inches thick, of buff-colored, pebbly silt. Below this there is a 24-inch layer of reddish-brown, sandy soil. The remainder of the deposit consists of 5 feet of alternating layers, about 2 inches thick, of red, pebbly silt and brown, medium to fine-grained sand. Both of these examples of pre-Wisconsin soils resemble those formed on Illinoian glacial deposits and the deposits in which these red colors have developed are assumed to be of Illinoian age. The soils consist of a thin, podsolized A-horizon, about 5 inches thick, presumably of post-Wisconsin age, lying upon a red B-horizon which is as yet only a slightly modified B-horizon of a pre-existing post-Illinoian soil.

TABLE 21. *Geologic Section in Gravel Pit, 0.4 Mile South of Thompsontown (m.86), Millerstown, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Sod and leaf mould, gray	0	1
2.	Silt, *Illinoian* (?), buff, pebbly; has platy structure	0	4
3.	Sand, *Illinoian*, light-colored, reddish-tan, pebbly; consists of streaks of red, silty clay interlaminated with buff sand	2	0
4.	Sand and gravel, *Illinoian*, red to tan, poorly sorted, coarse; consists of alternating layers of gravel in a red, silty matrix and tan-colored, medium- to fine-grained sand; boulders found at 1 foot above base	5	0
5.	Shale, Silurian Bloomsburg, red, compact. Exposed	8	0
	Total	15	5

Depth of leaching: at least 7½ feet
Depth of oxidation: at least 7½ feet

Some of the terraces, higher and clearly older than Illinoian, have soils which differ slightly in appearance from those of Illinoian age. The A-horizon is commonly light-gray in color and the B-horizon has a lighter color than that found in the Illinoian deposits. These soils impress one as having formed on materials which had already lost most of their original iron content by soil-forming processes before they were subjected to the peculiar weathering conditions of post-Illinoian interglacial time. Such a soil occurs ½ mile southeast of Mifflintown (m.119) on a hilltop about 160 feet above the Juniata River or 90 feet above the Illinoian terrace. The soil, identified by Shaw and others (1912) as belonging to the Holston series, consists of 12 inches of very loose, gray silt loam, underlain by 3½ inches of more compact, gray loam. Below it there is a very compact, red, silty clay, an old B-horizon. Other relics of pre-Illinoian soil occur within the periglacial region. However, they are often modified by the addition of younger deposits of loess or congeliturbate and evidence of their age is often obscure.

Summary.

The weathering of the unconsolidated Pleistocene deposits of the Susquehanna Valley varies with the length of time during which they have been exposed, as is shown in Figure 10 (p. 37). In general, the Valley Heads gravels are leached for 5 feet, the Binghamton gravels for 11 feet and the Olean gravels for 15 feet. Oxidation has progressed to a depth of 6 feet in the Valley Heads gravels, 12 feet in the Binghamton gravels and to depths in excess of 20 feet in the Olean gravels. The Wisconsin deposits were subjected to a different kind of weathering from that of the Illinoian deposits. Brown (and buff) soils formed during post-Wisconsin time on both Wisconsin and Illinoian deposits. The pre-Wisconsin deposits, however, bear the remnants of a red and yellow soil. There is some indication that the pre-Illinoian deposits were podsolized and leached of some of their iron before the red soils of post-Illinoian interglacial age began to develop. In general, the soils developed on the Valley Heads deposits have a 4-inch A-horizon and a 4-inch B-horizon; on Binghamton deposits an 8-inch A-horizon and a 10-inch B-horizon; on Olean deposits a 15-inch A-horizon and an 18-inch B-horizon. The soil developed on Illinoian deposits is a polygenetic soil and appears to consist of a 9-inch A-horizon and 13-inch B-horizon of post-Wisconsin age, superimposed upon the remnants of a pre-Wisconsin soil which was probably developed to a depth of 3 or 4 feet. Because of severe erosion, which occurred in the periglacial region during Wisconsin time, as discussed on pages 43 to 45, it is impossible to evaluate accurately the depth of development of the pre-Wisconsin soil. The soils developed upon pre-Illinoian deposits are the complex result of: (1) pre-Illinoian weathering, (2) pre-Wisconsin weathering, and (3) post-Wisconsin weathering.

Complex and composite soils, such as were discussed by Bryan and Albritton (1943), occur, in the Susquehanna Valley, either as the result of the burial of a soil by a newer deposit, followed by the weathering of the later deposit that penetrated the older soil, or as a result of a change in the weathering conditions, such, for example, as the podsolization of a red and yellow soil. In both instances the newer soil zones may be superimposed upon the older, and double soil horizons may be found, such as that at East Lemon (p. 40). If a soil is completely removed by erosion, a soil of the same type will redevelop, provided the weathering conditions have not changed; and its degree of development, as compared with similar surfaces elsewhere, will depend upon its age. If, however, erosion did not completely remove the B-horizon, the new soil will consist in part, of an eluviated B-horizon which may retain some of its original characteristics for a long period of time. This relationship is common among the soils developed upon Illinoian deposits.

The weathering history of a soil partially fills the gap in the Pleistocene history of the region, as determined from the glacial and periglacial deposits. Because of the distinctive characteristics of the soils it is possible under favorable conditions, to determine the age of a deposit, both within and beyond the limits of glaciation, by its soil development.

PERIGLACIAL DEPOSITS

GENERAL STATEMENT

Deposits of wind-borne, fine-grained sand and silt and masses of rubble produced and brought to place by severe frost-action occur throughout the Susquehanna River Basin, both in the glaciated and non-glaciated parts. These conspicuous types of deposit and many minor features of erosion testify to the severe climate which was periglacial to the ice sheets of Pleistocene time.

Few deposits of dune sand have so far been found. Wind-borne silt is, however, widespread. In some respects it is different from the typical loess deposits of the Rhine Valley or the Upper Mississippi Valley, for it is non-calcareous, non-fossiliferous, and commonly contains pebbles or rock fragments similar to those in the underlying materials. The presence of pebbles in the silt is the result of selective raising of the pebbles from below by frost-heaving, as has already been described by Steche (1933) and others. Some of the silt deposits lie on gravel outwash terraces adjacent to the rivers; and it may be argued that these silts are alluvial in origin. However, they are identical in appearance with deposits found high on the hillsides, well above any known river grade of the present or of the Pleistocene. If the silts of high altitudes cannot have been deposited by floods, they must have been deposited by wind. It would then appear than many of the silts at lower elevations may also be eolian.

The slopes of the hills and mountains tend to be broad, sweeping, and only slightly grooved surfaces with a gradient between 15 and 25 degrees. These slopes, now stable, must have developed at a time when the surface material was mobile, for they are covered by an evenly distributed deposit of rubble which extends into the valleys and beneath the sediments of the small creeks. The typical deposit, on the slopes of the sandstone and quartzite ridges, is composed of angular cobbles and boulders up to 3 or 4 feet in diameter, embedded in a matrix of smaller fragments, sand and silt. Similar material has been described in England (Mantell, 1833; De La Beche, 1839; Austen, 1851, 1857; Prestwich, 1892; Reid, 1892; Geikie, 1895), where it is called "head"; on the Continent (Beskow, 1930; Breuil, 1934; Büdel, 1937; Högbom, 1926); and in the Arctic and Antarctic regions (Anderson, 1907; Klute, 1927; Lewis, 1936; Poser, 1936). In the United States it has been recognized and described by Denny (1938). As will be brought out in later paragraphs, this mantle of coarse rubble is not due to current process, but is the common type of congeliturbate, of which there are many varieties. Where the congeliturbate has been formed by shale, a slope of shale fragments, which resembles a fine-grained "talus" or "scree", occurs in lieu of the coarser rubble. In drainageways on mountain slopes the finer constituents are removed from the rubble surface and a blockfield remains. Blockfields have been amply described (Darwin, 1839; Anderson, 1907; v. Lozinski, 1909, 1933; Högbom, 1926; Klute, 1927; Salomon, 1929; Ver Steeg, 1930; Ashley, 1933; Büdel, 1937; Smith, 1941, 1945), and their relationship to a severe periglacial climate well established.

EOLIAN DEPOSITS

Sand.

Deposits of wind-laid sand were found in a few places, notably along the left bank of the West Branch of the Susquehanna between Milton (m.133) and Chillisquaque (m.128), shown in Figures 12, 13-S_1 and 38 (pp. 50, 51, 106). Here there are low, gently sloping, rounded dunes, 10 to 15 feet high, separated by shallow, closed depressions. The dunes line the western margin of the Olean terrace and, to the east, the sand forms a surface mantle on the hills from 2 to 15 feet thick. In the eastern part of the village of Chillisquaque the eolian sand lies on a hilltop 130 feet above the river. This sand is fine-grained, well sorted, brown, and oxidized. It is free of coarser sand sizes and shows no distinct stratification. Its surface is now being eroded by the current processes of sheetwash and gullying, so that the A-horizon of the soil is only 4 inches thick and poorly developed. Gullies 1 to 2 feet deep are common on the sand-covered slopes.

On a hilltop half a mile north of Mahantango (m.104) and 139 feet above the river, there is another deposit of similar origin (fig. 13-S_2, p. 51). The hilltop is gently rounded and, on the north side near the top, there is a shallow, closed depression about 4 to 5 feet deep and 150 feet in diameter. The hilltop is covered by a mantle, 10 feet thick, of very fine sand, which contains sub-angular cobbles of white quartzite and medium-grained quartz conglomerate. A few quartzite boulders 2 feet in diameter were found. These rocks are thought to be derived from the "Montebello" sandstone which occurs locally. The sand is, in the upper 18 to 20 inches, buff-colored and clayey. Below this it is reddish-brown in color as though it had undergone Illinoian weathering. The sand grades, down the slopes, into a rubble derived from the underlying shale or sandstone, so that the surface forms a continuous, unbroken curve from top to bottom. This relationship is taken to indicate that the sand is older than the rubble and was moved down the hillside, as was the frost-riven rock, by congeliturbation.

Another deposit of very fine sand, shown in Table 22 (p. 49) and Figure 13-S_3, (p. 51), occurs above the left bank of Wiconisco Creek near Millersburg (m.96). It lies on a bench 80 feet above the river and is underlain by Mauch Chunk red shale. This deposit is 1 to 4 feet thick and consists of an upper, buff-colored, silty A-horizon, 4 to 6 inches thick, underlain by a brownish-red horizon that is so compact that it breaks into small lumps rather than grains.

TABLE 22. *Geologic Section in Road Cut on the North Flank of Berry Mountain, at Elevation of 460 Feet, ½ Mile South of Millersburg (m.96), Millersburg, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Sand, *Illinoian* (?), buff, loose, very fine-grained	0	6
2.	Sand, *Illinoian* (?), reddish-brown, very compact, very fine-grained	3	3
3.	Shale, Mississippian Mauch Chunk formation, red. Exposed	2	0
	Total	5	9

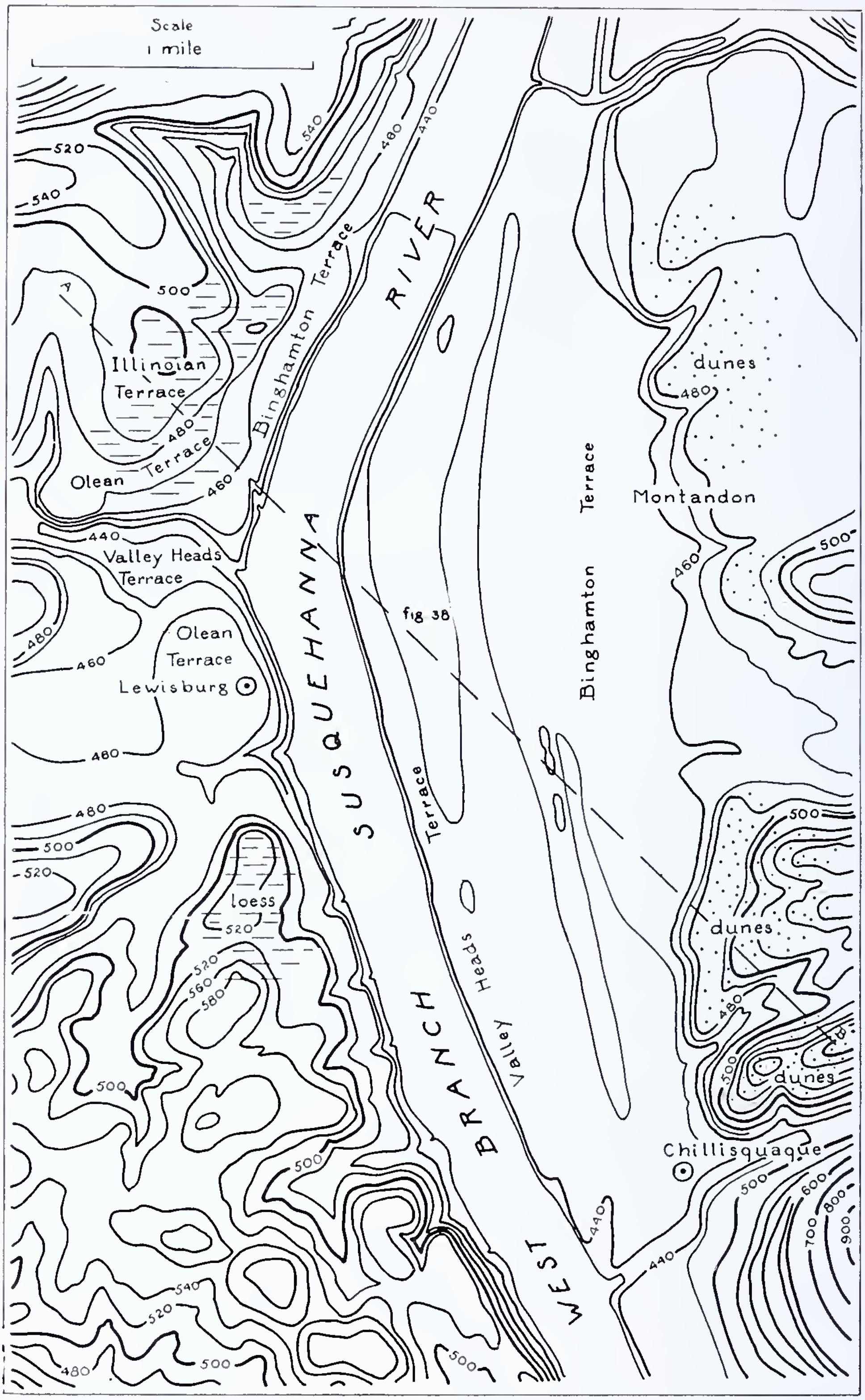

FIGURE 12. Topographic map of the valley of the West Branch, Susquehanna River near Lewisburg (m.130) showing position of terraces and of eolian deposits.

An insufficient number of deposits of wind-laid sand have been found to permit any generalizations concerning their origin or distinction as to age. It is likely that such deposits were formed during both Illinoian and Wisconsin time. The reddish sand masses may be Illinoian and the brown to buff-colored masses, such as occur near Chillisquaque, are almost certainly Wisconsin.

Loess.

Thin deposits of loess are widespread and common throughout the Susquehanna Valley. They are not restricted in elevation and have been observed up to 200 feet above the river. They weather readily and their age may easily be determined by their soil development. Those silts which lie well above the Illinoian terraces were clearly not deposited by floodwaters and must, therefore, be interpreted as wind-borne. These loess deposits lack several of the diagnostic characteristics of the Rhine Valley and Mississippi Valley loesses. They are non-calcareous and frequently occur at such a great distance from the nearest calcareous glacial deposit that it is doubtful if they ever contained any calcium carbonate. No gastropod shells have ever been found in them. They rarely exhibit vertical jointing or the columnar structure of loess. On the other hand, horizontal joints, closely spaced at ¼ to ½ inch apart, are commonly found near the surface. Pebbles, and sometimes even cobbles, are found scattered through the deposits. Such a pebbly loess was described by Leighton and MacClintock (1930). The presence of pebbles, in association with silt-sizes, cannot be explained by the current process of soil formation; nor can it be explained by any process involving running water, for the turbulence necessary to move the pebbles should certainly have swept the silt away. In each instance the pebbles resemble those found beneath the silt. The presence of these pebbles in the loess, and also the absence of vertical joints, are probably due to a stirring-up of the ground by frost-action during and after the deposition of the loess.

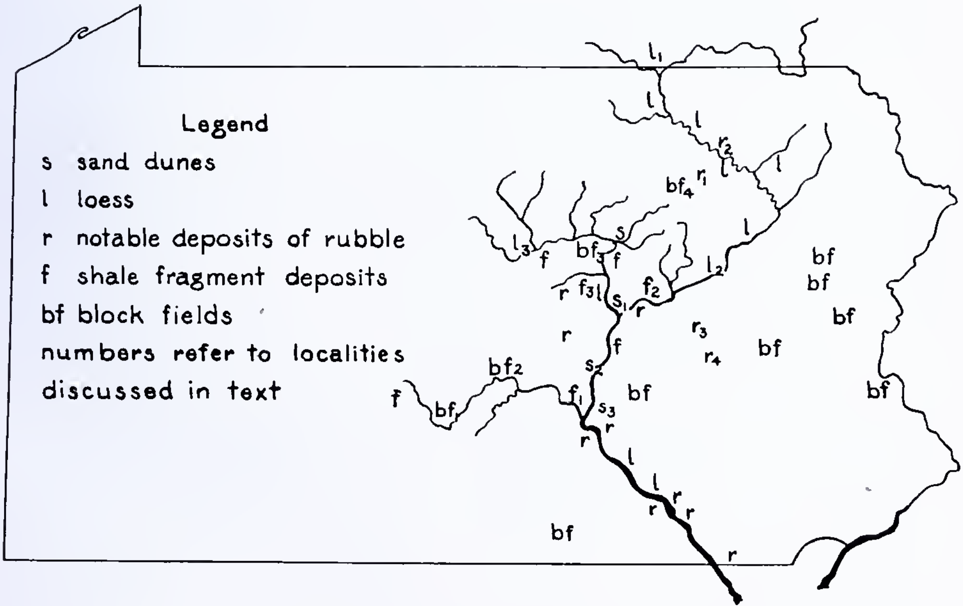
Legend
s sand dunes
l loess
r notable deposits of rubble
f shale fragment deposits
bf block fields
numbers refer to localities discussed in text
l1
l2
l3
r1
r2
r3
r4
s1
s2
s3
f1
f2
f3
bf1
bf2
bf3
bf4

FIGURE 13. Map of periglacial deposits in and near the Susquehanna Valley of Pennsylvania.

The most likely source for these loess deposits is the dust blown from the glacial outwash plains, as shown by Leighton (1932), and from the barren till and congeliturbate mantles of the region then peripheral to the ice (Zeuner, 1945). Loess deposits are common along the North Branch, West Branch and main stem of the Susquehanna River. They are less common along the Juniata River, which rises in an unglaciated region and carried no outwash. It follows, then, that the immediate and major sources were the successive outwash plains of the glacial rivers. As these outwash deposits are either non-calcareous or weakly calcareous and most of the local rocks are non-calcareous, the loess could never have contained much calcium carbonate. In nearly all instances the deposits of loess are thin and lie within the oxidized zone, so that any free calcium carbonate that they may once have contained has since been removed. These loess deposits are commonly found lying upon the unweathered surface of glacial till. One must suppose that there was insufficient time, between the deposition of till and loess, for the weathering of the till. In these instances the loess is a deposit of the same glacial substage as the till, and is glacial rather than interglacial or interstadial in age. The loess deposits in the non-glaciated regions are assumed to have been formed at the same time and, therefore, also to be glacial in age.

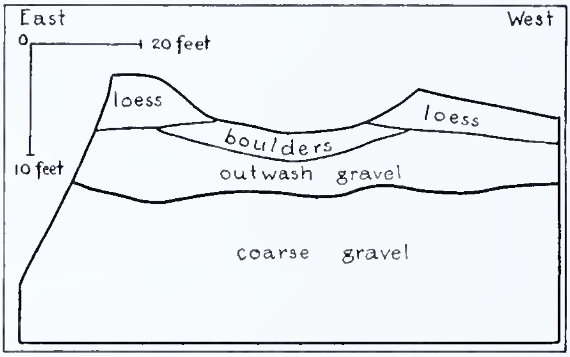

FIGURE 14. Relationship of materials exposed in gravel pit at foot of Spanish Hill near Waverly, N. Y.

The characteristics of these deposits are best shown by examples. An irregular deposit of loess, 4 to 5 feet thick, lies on both sides of a small drainageway on the north side of Spanish Hill (m.283), in the interfluve between the North Branch and the Chemung Rivers (figs. 13-L_1, and 14, pp. 51, 52). It covers (see Table 23, p. 53) a 4- to 6-foot layer of medium-grained, Binghamton outwash gravel. The surface of the drainageway is, beneath a mantle of sod, covered with a boulder pavement composed of a 1-foot layer of closely packed, platy cobblestones and boulders, horizontally oriented and free from interstitial, fine-grained material. It follows the surface of the outwash gravel, for a few feet, beneath the loess. The loess may, however, be older than the block pavement and have slumped down over it.

A terrace, 1 mile east of East Towanda (m.262), 27 feet above the Susquehanna River, is composed, as shown in Figure 15 (p. 53) and Table 24, (p. 54), of an upper layer of buff silt, 3 to 9 inches thick,

TABLE 23. *Geologic Section in Gravel Pit in the North Side of Spanish Hill, 1 mile Southwest of Waverly, Waverly, N. Y., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loess, *Binghamton,* buff, leached, oxidized	4	0
2.	Boulder pavement, *Binghamton,* composed of horizontally oriented, platy cobblestones and boulders; open voids	1	0
3.	Gravel, *Binghamton,* tan, silty, leached, oxidized	4	0
4.	Gravel, *Binghamton,* tan, coarse-grained, poorly sorted, leached, oxidized. Exposed	5	0
5.	Covered, to base	5	0
	Total	19	0

Depth of leaching: at least 14 feet
Depth of oxidation: at least 14 feet

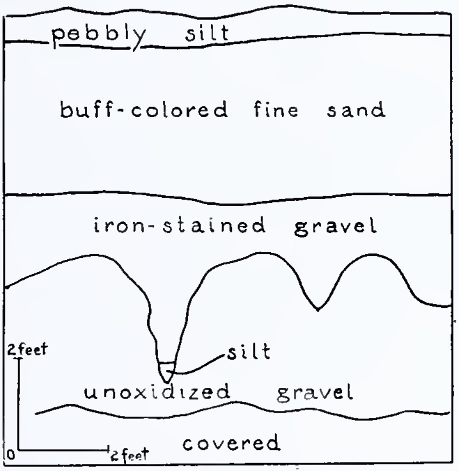

FIGURE 15. Relationship of materials exposed in gravel pit (m.262) near Wysox.

containing pebbles ½ inch in diameter in unoriented distribution; a layer of buff-colored, fine sand, 3½ feet thick, containing scattered pebbles ½ inch in diameter distributed in such a manner as to suggest cross-bedding; and a layer of fine-grained gravel, in a sandy matrix, and interbedded thin sand, of which 3 to 4 feet are exposed. The gravel is separated by a sharp contact from the overlying deposit. A brown, iron-stained zone, at least a foot thick, lies below the top of the gravel. The base of this zone is irregular and contains wedges or fingers which are up to 2 feet wide at the top and extend downward for as much as 5 feet. At the bottom of some of these wedges there is a 2-inch deposit of silt similar to that which covers the terrace. The wedges represent permeable zones in the soil which, since they contain silt, must have been open after the deposition of the overlying sand. As they were open to receive the silt, the effect of plant roots in producing permeable zones is discounted here. The permeable zones were probably produced either by tension attendant upon slumping or settling; or by the action of frost wedges as described by Leffingwell (1915) and others; or by both. The depth of oxidation varies between 5 and 10 feet. The deposit is leached of calcium carbonate to a depth of 5½ feet, except in the oxidized wedges, which are completely leached.

TABLE 24. *Geologic Section in Gravel Pit, 1¼ Miles East of East Towanda (m.262), Towanda, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loess, *Valley Heads*, buff, pebbly, leached, oxidized	0	6
2.	Sand, *Valley Heads*, buff, fine-grained, pebbly, leached, oxidized; cross-bedded	3	6
3.	Gravel, *Valley Heads*, brown, fine-grained, sandy, leached, oxidized; medium-grained sand matrix, irregular base	1	6
4.	Gravel, *Valley Heads*, gray, fine-grained, sandy, unleached, unoxidized; contains thin layers of medium-grained sand. Exposed	3	0
	Total	8	6

Depth of leaching: 5½ feet
Depth of oxidation: 5½ feet

Near Falls (m.205) a deposit of loess, which varies from 12 to 28 inches in thickness (fig. 11, p. 40), lies unconformably upon a sand and gravel deposit of Olean age. The soil here was described by Hendrickson and others (1929) as the Chenango gravelly loam. Some erosion of the Olean outwash prior to the deposition of the loess is indicated by the truncation of the bedding of the sand beneath the loess. As discussed on page 39, the degree of soil development indicates that the loess is probably of Olean age. Bodies of loess of similar characteristics and soil development were found near Falls at altitudes up to 400 feet above the river.

As is shown in Figure 16 (p. 54), loess lies unconformably upon the coarse gravel of an Olean kame terrace at a locality below Shickshinny (m.166). A soil profile has developed comparable to that found at Falls and on other Olean deposits and it is presumed to be of late Olean age. The pre-loess erosion shown in this section, therefore, represents no great lapse of time. The surface of the kame gravel deposits must have been modified, as soon as deposition was completed, by erosion that must have progressed at a more rapid rate than may now be observed in Pennsylvania. This erosion and the ensuing deposition of the loess were presumably complete before the end of the Olean glacial sub-stage.

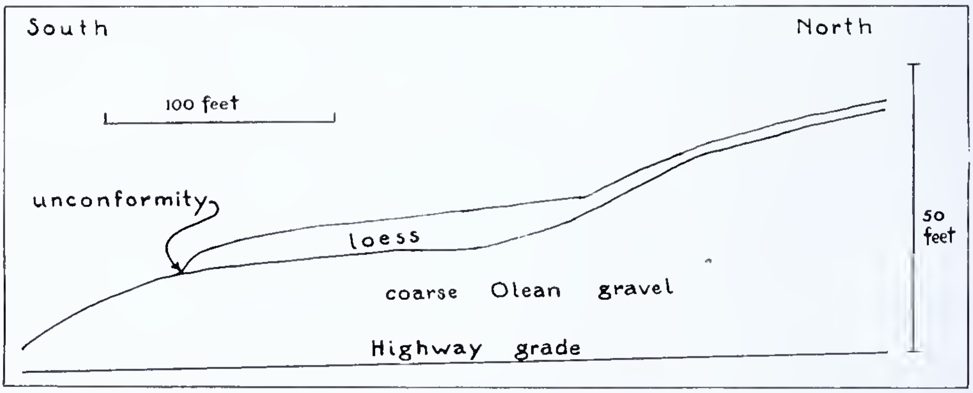

FIGURE 16. Relationship of materials exposed in road cut along U. S. Highway 11 near Shickshinny (m.168).

Along the North Branch south of the ice-front deposits at Berwick (m.157), (fig. 13-L_2, p. 51), along the West Branch, and along the main stem of the Susquehanna River, loess deposits have been observed at localities up to 200 feet above the river and they probably occur at higher levels. They overlie Illinoian till and outwash and overlie or are mixed with congeliturbate of Wisconsin age. On the basis of the criteria previously explained, these bodies of loess are of both Wisconsin and Illinoian age.

At Selinsgrove (m.116) loess occurs overlying Illinoian till and gravel 100 feet above the river. At Millersburg (m.96) it was found up to 210 feet above the river. At Harrisburg (m.70) and Marietta (m.44) all terraces above the Binghamton are capped with a silty deposit which Bashore (1894) regarded as useful for brick clay, although it is not now so used. These clayey silts may be slightly weathered, clayey loesses. At Marietta the Illinoian gravel terrace and, also, the lowest pre-Illinoian terrace, are covered with loess having typical post-Illinoian weathering.

Loess of both Wisconsin and Illinoian age is exposed on the West Branch along Highway 220, 1 mile east of Dunnstown (m.188), (fig. 13-L_3, p. 51). Here, in a gully on the hillside, there is a series of thin, weathered deposits, which are described in detail in Table 25 (p. 55).

TABLE 25. *Composite Geologic Section in Road Cut and Gully on the North side of Highway 220, 1 mile east of Dunnstown, Lock Haven, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loam, *Recent* (?), tan, silty, loose, friable	0	4
2.	Loam, black, silty, friable	0	1 to 1½
3.	Loam, *Wisconsin*, light-brown, silty, contains more clay and is darker-colored than number 1. A buried A-horizon	0	5
4.	Silt, *Wisconsin*, buff, clayey, compact, contains pebbles. Slightly mottled by brown iron stains. A buried B-horizon	0	11
5.	Clay, *Illinoian*, brownish-gray with greenish cast, pebbly, jointed, with horizontal brick-red streaks. A buried A-horizon	2	0
6.	Clay, *Illinoian*, brick-red, pebbly, crumbly. A buried B-horizon	1	8
7.	Silt, *Illinoian*, buff, slightly clayey, pebbly. Pronounced horizontal joints spaced at ½-inch intervals. A weathered loess	0	8
8.	Silt, *Illinoian*, light-brown to buff, pebble-free, jointed. Very rusty along joints; blue-gray in spots between the joints. A weathered loess	0	10
9.	Silt, *Illinoian*, greenish-gray, clayey, pebble-free, jointed. Oxidized along the joints	0	15
10.	Sand, *Illinoian*, grayish-white, very fine, horizontally jointed, contains no clay or pebbles. Speckled with small brown iron spots and with black spots and smears. Non-calcareous. To base	2	10
	Total	11	0

Non-calcareous

Depth of oxidation: irregular, varies between 6 feet 1 inch and 8 feet 2 inches

The difference in the amount and kind of the weathering suggests that they were deposited at different times, separated by intervals during which weathering took place. According to this criterion, the upper 22 inches of the deposit (horizons 1 to 4) was laid down in Wisconsin or post-Wisconsin time. The immediately underlying materials (at least horizons 4 and 5) were weathered during the post-Illinoian interglacial stage, when red colors were developed, and are Illinoian in age.

At the surface there is a 4-inch deposit of loose, tan-colored, silty loam. Its significance is obscure, for it lies upon the sequence of soil zones usually associated with Wisconsin loess deposits. It may either be a very late loess deposit, younger than Binghamton in age, or it may have been deposited by slope wash. Below this there is a characteristic profile of Wisconsin soils: A-1 horizon 1 to 1½ inches, black, humus soil; A-2 horizon, 5 inches, light-brown, silty loam; B-horizon, 11 inches, buff-colored, silty, pebbly clay, to which brown, limonitic stains have imparted a slightly mottled appearance.

Below the Wisconsin soil there is a jointed, pebbly clay layer, 2 feet thick. It is brownish-gray in color, with a greenish cast, and is marked by horizontal streaks of brick-red. In many respects it resembles the brown layer at a depth of 3 to 5 feet found in the Illinoian gravel at New Columbia (p. 43), for the brown color is developed and there is a red staining which forms a transition into an underlying red layer. It is probably the A-horizon of the post-Illinoian soil and is underlain by a 20-inch layer of brick-red, pebbly clay similar to that interpreted as the post-Illinoian B-horizon at Selinsgrove (p. 44).

Three layers, representing varying degrees of oxidation, underlie the B-horizon of the post-Illinoian soil. The uppermost of these layers, 8 inches thick, is buff-colored, jointed, pebbly silt; the second, 10 inches thick, is a light-brown to buff-colored silt in which the blue-gray color of unoxidized loess is apparent between the joints. This layer, and all which are exposed below it, are free from pebbles. The lowest silt layer, 15 inches thick, is greenish-gray in color and shows brown stains only along the joints. At the bottom of the exposure there is at least 34 inches of grayish-white, unoxidized, very fine sand or coarse silt. It is non-calcareous and free from clay and pebbles. It contains spots of brown limonite and, like some Upper Mississippi Valley loesses, black spots and smears such as might be formed by specks of carbon. Horizons 7 to 10 of this deposit are the weathered C-horizons of the post-Illinoian soil. All of the material appears to be wind-borne silt and fine sand of Illinoian age.

A weathered silt or fine sand deposit, which may be a loess of Illinoian or pre-Illinoian age, occurs beneath a thick deposit of rubble on Jacks Mountain near Mapleton (m.163) on the Juniata River. It is described on page 63.

RUBBLE

The rubbles of the Susquehanna Valley are congeliturbates, composed of unsorted rock fragments of all sizes from boulders or slabs 6 to 8 feet in diameter down to silt or clay. This material has been transported down slopes, and has become stabilized in transit or has accumulated at the base of slopes on terraces or on the valley floor. The slopes which are mantled with rubble are long, smooth and unbroken. In this area they rarely exceed 23 degrees and some are as low as 2 degrees. Their inclination is dependent upon the viscosity and, therefore, the speed with which the material flowed. The deposits of at least two stages of congeliturbation, Wisconsin and Illinoian, may be distinguished by their weathering.

Congeliturbate in Areas that were Glaciated.

Within the area covered by the Olean ice, till-mantled slopes are smooth and must have been modified from the original ice-moulded topography. The slopes are covered with congeliturbate derived from the till. It may be distinguished from the underlying till by the following differences:

1. It has open voids and is loose-textured; whereas the same till, when undisturbed, is compact.
2. It has no jointing; whereas the undisturbed till tends to have a prismatic joint system.
3. The platy pebbles and cobbles, particularly the larger pieces, tend to be oriented with the longer axes parallel to the gradient of the surface slope; whereas orientation within the undisturbed till is related to the local direction of ice movement, and is also much less noticeable.

The distinction between disturbed and undisturbed till, here described, is not to be confused with the division of till into superglacial and basal tills described on page 22. The division of the tills is made on the basis of differences in the coarseness of the till matrix. The distinction between disturbed till, or congeliturbate derived from till, and undisturbed till is made on the basis of the till structure. A congeliturbate may be derived from either superglacial or basal till.

In the periglacial region, south of the Olean ice front, the congeliturbates are mostly derived from the break-up of bedrock. However, the foregoing characteristics are apparent in those of Wisconsin age, but not in those of Illinoian age for, in the latter, the voids have been filled by fine soil material produced by weathering and the orientation of the rock fragments has been destroyed by the milder frost-heaving of Wisconsin time.

TABLE 26. *Geologic Section in Road Cut on U. S. Highway 6, 3 Miles West of North Towanda, Sayre, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Rubble, *Olean* (?), buff, silty, stony, leached, oxidized; consists of disturbed Olean till; platy boulders oriented parallel to slope; open voids	8	0
2.	Till, *Olean*, buff, silty, bouldery, leached, oxidized. Exposed	7	0
3.	Covered	4	0
4.	Till, *Olean*, blue-gray, silty, calcareous, unoxidized; contains striated pebbles	3	0
5.	Till, *Olean*, yellowish-brown, silty, calcareous, oxidized	3	0
6.	Till, *Olean*, blue-gray, silty, calcareous, unoxidized	18	0
	Total	43	0

Depth of leaching: about 17 feet
Depth of oxidation: about 17 feet

On the left bank of Sugar Creek, 3 miles west of North Towanda (m.267), described in Table 26, (p. 57), the undisturbed Olean till is overlain by a layer of congeliturbate which varies from 7 to 10 feet in thickness. This material resembles the underlying till, but contains a concentration of platy boulders oriented parallel to the slope, and open voids which occur scattered throughout the deposit. It has moved downhill to its present position from a still undetected body of till which presumably exists or once existed uphill.

Along Mehoopany Creek, 42 miles to the south, two similar deposits are exposed. On the right bank, 1¼ miles east of Forkston (fig. 13-R_1, p. 51), as is shown in Table 27 (p. 58), a poorly sorted gravel deposit of an Olean kame terrace is overlain by 2½ feet of buff, silty rubble composed chiefly of angular, platy cobblestones. Open voids are present.

TABLE 27. *Geologic Section in Road Cut on Highway 87, 1¼ miles east of Forkston, Meshoppen, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loess, *Binghamton* (?), buff, leached, oxidized; contains angular cobbles	3	0
2.	Rubble, *Binghamton* (?), buff, silty, leached, oxidized; composed of angular cobblestones; open voids	2	6
3.	Gravel, *Olean*, brown, coarse-grained, poorly sorted, sandy, leached, oxidized; composed of rounded pebbles and cobbles	6	0
4.	Sand, *Olean*, brown, very fine-grained, pebble-free, leached, oxidized; in sharp contact with horizon 5	9	0
5.	Gravel, *Olean*, red to reddish-brown, coarse-grained, silty, leached	2	6
6.	Gravel, *Olean*, red to reddish-brown, coarse-grained, silty, calcareous, unoxidized, exposed	12	6
7.	Covered, to base	10	0
	Total	45	6

Depth of leaching: 22 feet
Depth of oxidation: about 20 feet

Two and one-half miles downstream, on the left bank, a thick deposit of Olean till is overlain by 7 feet of congeliturbate. Table 27 (p. 58) shows this deposit as complex and consisting of an irregular surface layer, 1 to 2 feet thick, of buff-colored, stony loess, underlain first by a 3-foot layer of loose, bouldery, buff-colored, disturbed till, and then by 2 feet of red, bouldery, disturbed till. The stony loess at the surface is probably a disturbed phase, and is identical in age with the buff-colored, pebble-free loess which lies between the till and the congeliturbate. In this locality the process whereby the congeliturbate moved down the slope did not involve thorough mixing, for the different layers retain their identity. The congeliturbate must, therefore, have slid downhill as a body and it may be assumed that, here, the congeliturbate was produced more by the relatively slow sliding of a partly melted surface mass containing still frozen portions than by the relatively rapid movement of a completely melted and semiliquid mass. This process took place after the deposition of the loess, assumed to be of Olean age, possibly during an ensuing cold period of the Binghamton glacial sub-stage.

The best evidence relative to the age of a rubble deposit can be gleaned from features displayed at the Vosburg Railroad Station (m.218), (fig. 13-R_2, p. 51), 1200 feet from the left bank of the river.

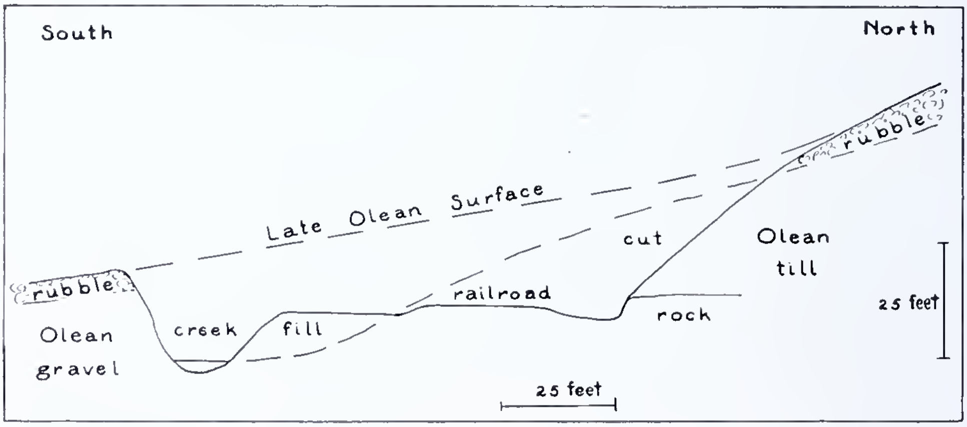

FIGURE 17. Relationship of rubble to Olean till and gravel at railway station, Vosburg (m.218).

Here a creek and a railroad cut have opened a series of exposures, as shown in Figure 17 (p. 58). In the creek bank a deposit of valley train gravels of the Olean type, 10 feet thick, is overlain by 5 feet of rubble composed of large, angular and rounded boulders, cobblestones, pebbles, silt and clay. It is a mixture of Olean till and fragments of the local country rock. The soil developed on this material was described by Hendrickson and others (1929) as the Wooster gravelly loam. South of the Railroad Station a similar deposit overlies the Olean till, and the deposit which overlies the gravel must have moved down the hillside during post-Olean erosion of the hill. Since that time the creek has cut 20 feet below the top of the rubble.

The top of the gravel is 37 feet above the Susquehanna River. This is distinctly below the level of the Binghamton terrace, which here is 45 feet above the river, and more nearly the level of the Valley Heads terrace at 33 feet. Therefore, the erosion surface at the top of the Olean gravel appears to be graded to the level of the Valley Heads terrace. This relationship raises the question as to whether the gravels are of Olean age or are of Valley Heads age. It is possible that they were reworked from the Olean terrace gravels during the Valley Heads sub-stage, but their bedding, weathering, and the erosion surface at the top all indicate that they are of Olean age. Since deposition, they were eroded to a slope leading to the elevation of the Valley Heads terrace.

The event of congeliturbation and the deposition of the rubble is, therefore, limited to the time between the Valley Heads stage and the period of the downcutting of the creek, a Mankato or Recent event, and consequently must have taken place during the Late Wisconsin. Presumably the rubble deposit is Valley Heads or Cary in age.

Congeliturbate in Unglaciated Regions

Congeliturbation was equally effective in those regions near, but outside of, the ice margin. Here the heterogeneous mixing of material of all sizes has produced rubble deposits which resemble glacial till, by reason of their heterogeneity in grain size and lack of bedding. The fragments which make up these deposits vary in coarseness and lithology with the bedrock. All or nearly all have been broken off by frost-action and are, therefore, congelifracts.

The deposits occur at all elevations from the mountain tops down to within 40 feet of the river. No congeliturbate was found on the Binghamton terrace along the lower part of the Susquehanna River Valley, and it is postulated that, here, the climate was less severe during the latter part of the Wisconsin than during the earlier glacial sub-stages.

At Herndon (m.110) there is a 10-foot deposit of unconsolidated material of probable Wisconsin age, lying about 60 feet above the river on weathered Devonian sandstone, as described in Table 28 (p. 60). The upper part of the deposit, 3 to 8 feet thick, is composed chiefly of buff-colored, clayey, weathered silt with gray and reddish-brown streaks, and contains angular pebbles and cobbles. It is a loess which has been modified by congeliturbation and into which rocks from below have been incorporated. Below this there is a thin, irregular layer of buff-colored rubble containing all sizes from silt up to cobbles 8 inches in diameter, and underlain by a layer, 1 to 2 feet thick, of rock fragments of cobble size, between which the voids are open.

TABLE 28. *Geologic Section in Excavation on east side of Highway 14 at Herndon, Millersburg, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loam, black, silty	0	2
2.	Silt, *Wisconsin*, buff with gray and reddish-brown streaks. Probably a loess which has acquired angular cobbles and boulders by congeliturbation	3 to 8	0
3.	Rubble, buff, stony, clayey, unsorted, contains angular boulders up to 8 inches in diameter	0 to 2	0
4.	Sandstone fragments, angular, 1 to 2 inches in diameter, open voids	1 to 2	0
5.	Sandstone, weathered, oxidized on surfaces	3 to 5	0
6.	Sandstone, Middle Devonian, black, unweathered. To base	0 to 4	0
	Total	7 to 21	0

This layer is the shattered surface zone of the underlying rock, and it is supposed that any fine-grained weathering products which may have formed in it have been removed by percolating water. The fragments in this zone are essentially unweathered and, because the zone is not penetrated by the overlying rubble, must have formed after the rubble reached its present position. Probably the freezing of water, which seeped below the surface, led to the shattering of the rock. Below the shattered zone the rock is oxidized along the joints for a depth of 3 to 5 feet. A similar zone of rock fragments with open voids was described by Gilbert and others (1916) as characteristic of the Manor Stony loam and Manor Slate loam in Lancaster County.

At Millersburg (m.96) the slope, from the crest of the upland 166 feet above the river down to within 55 feet of the river, is mantled by a rubble deposit 6 to 8 feet thick. The upland, described on page 112 as a remnant of the Harrisburg peneplain, is covered with a thin mantle of angular rock fragments in a silty matrix. These fragments are congelifracts of glacial age and appear to lie near their parent rock. On the slope, however, evidence of movement is clear for, at a point 90 feet above the river, a 6-foot-thick deposit of rubble, composed chiefly of red shale, lies upon an outcrop of red sandstone.

On the south flank of Bald Eagle Mountain, 2 miles northwest of Montgomery (m.145), a deposit of deeply weathered, red, clayey, Illinoian till, containing white quartzite boulders and shale pebbles, is overlain by 4 feet of congeliturbate, the lower 2 feet of which is buff-colored, stony silt loam and the upper 2 feet a stony silt. Tuscarora quartzite boulders occur throughout the congeliturbate. There is no break in gradient of the slope between the lower till- and rubble-covered surface and the rubble-covered mountain slope above. One must suppose that the whole slope from the mountain top to its base and the attendant rubble cover are the products of post-Illinoian time. The original topography of the Illinoian till has been removed by the same process which formed the mountain slope and the rubble. Thus the congeliturbate lying upon the Illinoian till and on the bedrock slope above moved downward from the adjacent mountain slope in post-Illinoian or Wisconsin time.

Congeliturbate, at least 2½ feet thick, consisting of red sandstone and siltstone, lies on the Illinoian terrace 1½ miles southwest of New Buffalo (m.88). The terrace deposit is composed of 2 to 3 feet of brown, rusty silt with sand lenses and pebbles, including a pink granite pebble about 3 inches in diameter. The rubble extends in an unbroken slope from its parent outcrop down the hill and onto the Illinoian terrace. Thus the rubble is certainly post-Illinoian in age.

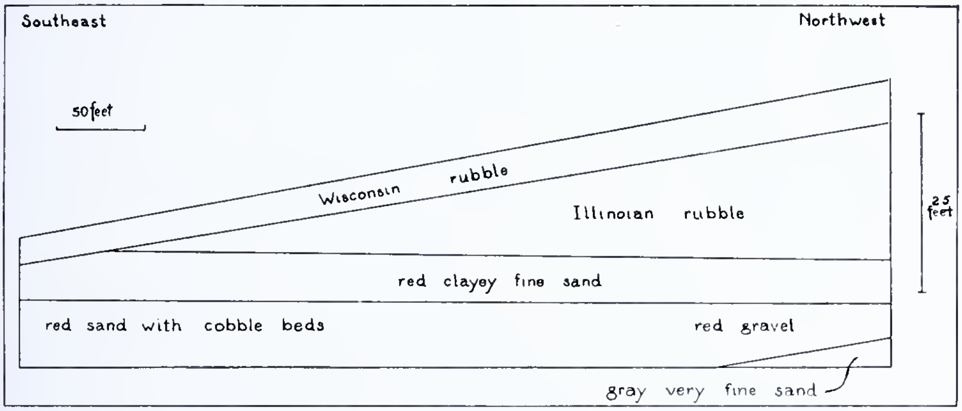

FIGURE 18. Idealized geologic cross-section of hillslope near east bank of Chatham Run at Charlton (m.184).

At Charlton on the West Branch (m.184) a deposit, shown in Figure 18 (p. 61) and Table 10 (p. 27), of rusty-brown, Illinoian gravel, is overlain by about 25 feet of rubble which is divisible into two parts. The upper 6 feet is a grayish-to-buff-colored mass while below, the rubble is red as though it had undergone the same weathering which imparted a red color to the Illinoian glacial deposits. The congeliturbate at this place probably represents deposits of both Illinoian and Wisconsin time.

The largest and most spectacular exposure of congeliturbate which has so far been found in the Susquehanna Basin may be seen in a

TABLE 29. *Composite Section in Road Cut along U. S. Highway 22, in Jacks Mountain opposite Mapleton, Mt. Union, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loam, black, silty, clayey	0	2
2.	Rubble, *Wisconsin*, tan, clayey with pebbles	1	0
3.	Rubble, *Illinoian*, mottled brick-red and ash-gray, stony, clayey, very compact, with boulders	3	0
4.	Rubble, *Illinoian*, mottled red and gray with greenish-gray spots, clayey, compact, contains fewer boulders than rubble above or below. Grades downward into:	0 to 15	0
5.	Rubble, *Illinoian*, mottled red and gray, clayey with abundant angular pebbles and cobbles. Some boulders	10	0
6.	Silt, *pre-Illinoian* (?), red, compact, upper part contains some clay	15	0
7.	Sand, *pre-Illinoian* (?), buff-colored to rusty, well sorted, fine-grained. Contains limonite concretions	3	0
8.	Sand, *pre-Illinoian* (?), buff, well sorted, fine-grained, cemented by manganese in ½-inch-thick layers	6	0
9.	Sand, *pre-Illinoian* (?), buff-colored to rusty, fine-grained, well sorted	1	0
10.	Gravel, *pre-Illinoian*, rusty, coarse, sandy, contains rounded pebbles and cobbles, limonite cement and limonite concretions	2 to 5	0
11.	Gravel, *pre-Illinoian*, gray, unoxidized, silty, contains pebbles and cobbles up to 3 inches in diameter	0 to 3	0
12.	Shale, olive-green, Silurian (Clinton formation), sharply beveled at an estimated altitude of 737 feet above sea level or 177 feet above the river. Surface unweathered and contact with gravel sharp. Exposed.	10	0
	Total	70	2

Non-calcareous
Depth of oxidation: 56 feet

road cut on U. S. Highway 22 on the west flank of Jacks Mountain near Mapleton (m.163). This exposure is illustrated by a contour map (fig. 19, p. 62), a cross-section (fig. 20, p. 63), and a geologic section (Table 29, p. 61). At this place about 30 feet of congeliturbate overlies 25 feet of silt and fine sand, probably of eolian origin. This, in turn, lies on 5 feet of coarse gravel which blankets a terrace cut in rock. The congeliturbate is an unsorted rubble of angular rock fragments in a matrix of silt and clay. When slicked, this matrix reveals the presence of coarse grains, as does glacial till. However, till structure and striated stones are lacking and it is composed entirely of fragments of Lower Silurian quartzite, sandstone and shale from rocks which occur on Jacks Mountain. The upper foot of congeliturbate (No. 2 in Table 29, p. 61) is buff to tan in color. It is similar in weathering to other deposits attributed to the Wisconsin stage and was probably laid down during that time. The remainder of the congeliturbate (Nos. 3, 4 and 5 in Table 29, p. 61) is mottled brick-red and gray, compact and clayey, so that when dry it tends to break out in lumps. Because it has been weathered to a red color it must have been subjected to pre-Wisconsin weathering and must be at least Illinoian in age. It is composed of three zones: an upper and a lower zone which are coarse and contain abundant cobbles and some boulders, separated by a relatively fine-grained rubble. The upper

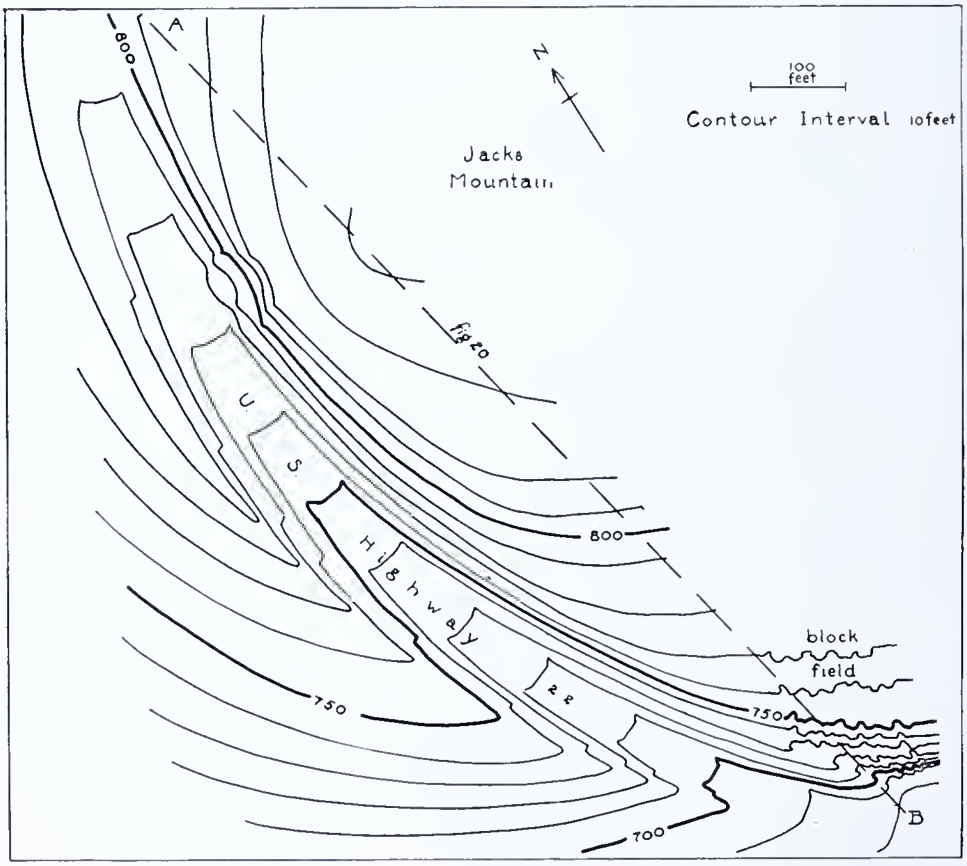

FIGURE 19. Topographic sketch of road cut of U. S. Highway 22 in Jacks Mountain near Mapleton Depot (m.163) showing position of Figure 20.

coarse zone lies at the base of the Wisconsin congeliturbate and, during the pre-Wisconsin interglacial stage, formed the surface of the ground. During this time, and particularly immediately following the stabilization of the ground before vegetation completely covered the slope, the fine-grained particles were washed from the surface of the congeliturbate, leaving a concentration of boulders and cobbles. The upper coarse zone is, then, a boulder-strewn slope, such as is described on pages 69 to 73, that has been buried. The lower coarse zone may possibly be of similar origin. Such an interpretation implies that the upper 15 feet of rubble was separated from the lower 10 feet by a time interval during which erosion occurred. Two distinct cold periods, rather than one, are then required to explain this deposit. On the other hand, it brings the quantity of congeliturbate deposited at any one stage more closely into accord with that observed elsewhere in the valley.

At the western side of the exposure there is a zone of dark-red congeliturbate composed of small fragments, about ¼ inch in diameter, of red shale and olive-green shale, and larger fragments of red shale and red sandstone, about 1 inch in diameter, enclosed in a red, clayey matrix. This was probably derived from the Bloomsburg formation. The contact between the red and the adjacent buff congeliturbate is sharp and shows that there was little mixing between parallel flowlines as the rubbles moved down the slope.

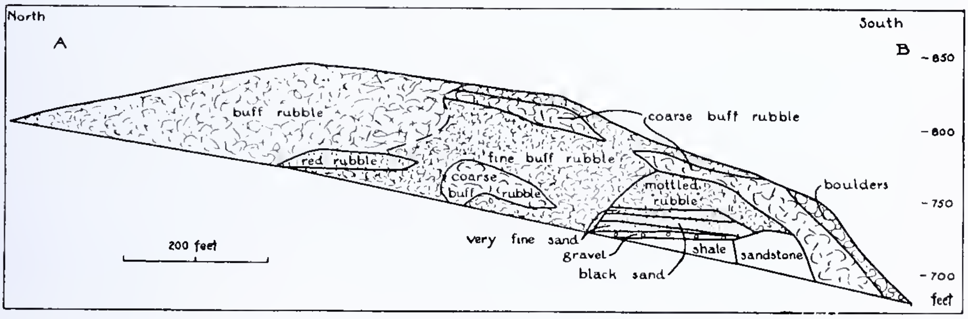

FIGURE 20. Geologic cross-section of east bank of road cut in Jacks Mountain near Mapleton Depot showing gravel- and sand-covered rock bench overlain by rubble.

The red silt which lies just below the congeliturbate (No. 6 in Table 29, p. 61) is probably a loess, for it is well sorted, contains no pebbles, and shows no stratification. It is no younger than Illinoian and possibly older, for it lies beneath a rubble identified above as Illinoian. The upper part of the silt is clayey and may be a buried soil, weathered when the top of the silt formed the surface of the ground at 758 feet above sea level.

The fine-grained, rusty sand underlying the silt is well sorted and shows no distinct stratification. It, also, may be a wind-borne deposit. However, it is distinct, in the kind of weathering, from the overlying silt and is similar to the underlying gravel, which still has some unoxidized patches. The gravels, 180 feet above the river, correlate, on the basis of height, with gravels found in a col, 200 feet above the right bank of the river near Vineyard (m.151) and with some rounded cobbles about 158 feet above the river, or 620 feet above sea level, at Anderson (m.138). A projection of these three points to Lewistown (m.130) falls at about 600 feet above sea level, or at the height described by Ashley (1933) as that of the Harrisburg surface.

Shale-Fragment Slopes

On those slopes where the underlying rock is composed almost entirely of shale or closely jointed, platy sandstone, a talus-like apron of congelifractate may form. In many instances, where the congelifractate contained a sufficient quantity of fine-grained particles to retain the soil moisture, a *pergelisol*[1] formed. Seasonal melting and the development of a *mollisol*[2] at the surface led to the downhill movement of the muddy, surficial mass. That this motion was generally more rapid than that of the coarser congeliturbates is inferred from the fact that the slopes of such fine-grained congeliturbates are frequently more gentle than those of the coarser material.

A section in a shale-fragment slope is exposed in a pit on U. S. Highway 22 above the left bank of the Juniata River opposite Losh Run (m.88) (Table 30, p. 64 and fig. 13-F_1, p. 51). The deposit is composed of angular fragments of Upper Devonian marine shale and flagstone. The pieces range in size from less than ½ inch in diameter to boulders 3 feet across. About 80 per cent of the pieces are estimated to be less than 1½ inches in diameter and less than 5 per cent exceed 1 foot. They are cemented together by buff silt and clay to form a compact body. The flat fragments are not as distinctly oriented here as in some other slopes of similar composition, and the whole deposit shows a rude, cross-bedded structure in which the banding, shown by alternation of coarse and silty layers, is gently curved and truncated by other bands. This cross-bedding is assumed to represent successive channels of mudflows and to indicate that this deposit was not laid down by a single movement, however slow and continuous, but was, instead, laid down by repeated flows of labile mud.

TABLE 30. *Geologic Section in Gravel Pit on U. S. Highway 22, above the left bank of the Juniata River opposite Losh Run, New Bloomfield, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Forest litter	0	1
2.	Shale fragments, buff, loose. Fragments average 1 to 1½ inches in major diameter	4	0
3.	Shale fragments, buff, compact, cemented by interstitial clay and silt. Fragments average 1 to 1½ inches in major diameter	3	0
4.	Shale fragments, buff, compact, composed chiefly of fragments 1½ inches in major diameter with cobbles and boulders up to 3 feet in diameter	2 to 3	0
5.	Shale fragments, buff, 1 to 1½ inches in major diameter, in layers 2 feet thick separated by zones 2 to 3 inches thick which have a greater concentration of interstitial clay. The layers are not parallel, but truncate one another as in cross-bedding	10	0
6.	Slumped, to base	20	0
	Total	40	0

---

[1] *Pergelisol* is permanently or perennially frozen ground. This word was introduced by Bryan (1946).

[2] *Mollisol*, introduced by Bryan (1946), is seasonally thawed ground above the pergelisol.

At a depth below the surface which varies from 0 to 7 feet, there is an irregular zone 2 to 3 feet thick which contains a larger proportion of coarse fragments than do the deposits either above or below it. This zone is analogous to the boulder zones in the congeliturbate on Jacks Mountain and may represent a short break in the sedimentary record.

The shale-fragment deposit extends down to within about 50 feet of the river or to the level of the Olean terrace. As is common with Wisconsin deposits, it has been deeply weathered to a buff color, but contains no red-stained zone. It is, therefore, interpreted to be Wisconsin in age. Most of it was probably laid down during the Olean glacial sub-stage, but some of the surface material may represent the mudflows of later cold periods.

On Montour Mountain (fig. 13-F_2 p. 51), 100 feet above the left bank of Mahoning Creek, ¾ mile north of Danville (m.134) on the North Branch, there is a deposit, described in Table 31 (p. 66), composed entirely of fragments of Rose Hill shale. Throughout most of the deposit the fragments, which are platy and usually less than 2 or 3 inches in major diameter, are oriented with their broadest surface dipping down the slope at an angle slightly lower than the 15-degree slope of the surface. In the zone between 2 and 6 feet below the surface the orientation of the fragments is disturbed. They are drawn down, until nearly vertical, near the edges of silty, wedge-shaped and irregular bodies shown in Figure 21 (p. 65). This contorted zone is the "warp" or "trail" of the English geologists. It was formed by frost-heaving and irregular movement within the mollisol. It indicates that, at the period when it was formed, the top of the pergelisol was 6 feet below the surface at this point, and that water drained from the 2-foot zone immediately below the surface before it could become involved

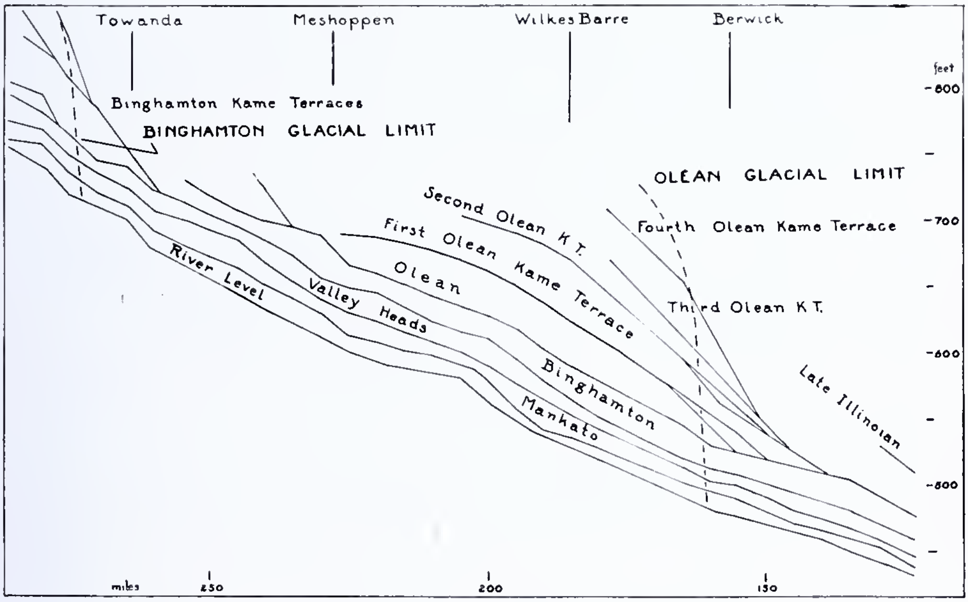

Figure 21. Vertical section in a shale-fragment slope near Danville (m.134) showing orientation of fragments.

in this process. Between these two limits lay a 4-foot zone which was frozen in winter and saturated in summer. This was the mollisol of that time.

TABLE 31. *Geologic Section in Pit in Montour Mountain above left bank of Mahoning Creek, ¾ mile north of Danville, Shamokin, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Pine needles	0	½
2.	Loam, black, silty, loose	0	2
3.	Shale fragments, *Wisconsin* (?), tan, loose, in silty matrix	0	2 to 8
4.	Shale fragments, *Wisconsin* (?), tan, composed of strong, slightly weathered fragments in silty matrix. Orientation of fragments strongly disturbed in lower 4 feet	5	0
5.	Shale fragments, *Wisconsin* (?), tan, strong, show distinct orientation parallel to the slope	5	0
6.	Shale fragments, *Illinoian* (?), red, weak, weathered, in a red, clayey matrix	10	0
	Total	20	5

At a depth of 11 feet below the surface there is a distinct change in the amount and kind of weathering of the shale fragments. Those above are only slightly weathered. The surface is oxidized to a buff color, but the interior of many remains sound and retains the olive-green to blue-green color of unweathered Rose Hill shale. Such lack of weathering can be explained only by assuming that, at the time of the formation of the talus, the fragments were broken from an unweathered rock surface, carried down the slope, and deposited before the initiation of chemical weathering. Such fragments or a deposit composed of such fragments cannot form under present-day temperate climatic conditions. One must assume that the fragments were produced in a climate characterized by strong mechanical disintegration of rock and lack of chemical decomposition, such as that of the sub-Arctic or of the periglacial region during a glacial stage.

Below this relatively fresh deposit the shale fragments are thoroughly weathered, lack their original strength, and lie in a red, clayey matrix. If they were once similar to those above, they have since undergone much more severe chemical weathering. This degree of weathering resembles that shown by deposits of Illinoian age. It appears, therefore, that the lower part of this mass of shale fragments was laid down during the cold period of the Illinoian glacial stage and was subjected to the severe weathering of the pre-Wisconsin interglacial stage. The upper part of the deposit has the weathering phenomena of Wisconsin deposits and appears to be the result of the periglacial climate of Wisconsin time. On the other hand, the deposit is so thick that its upper part is well drained and continually above the water table. It may be that the upper part is also of Illinoian age, but escaped the chemical weathering and rubification of pre-Wisconsin weathering. Such a suggestion, however, seems without good foundation.

A similar deposit occurs above the right bank of Buffalo Creek near Ramsey School (fig. 13-F_3, p. 51), 4¼ miles west of New Columbia (m.135) as described in Table 32 (p. 67). The fragments, composed of Rose Hill green shale, occur in two horizons. The upper horizon, 8 to 10 feet thick, contains relatively fresh, buff-colored frag-

TABLE 32. *Geologic Section in Pit on right bank of Buffalo Creek near Ramsay School, White Deer Township, 4¼ miles west of New Columbia.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loam, black, silty, loose	0	2
2.	Loam, buff, silty, loose	0	6
3.	Shale fragments, *Wisconsin* (?), buff, strong, slightly weathered	8 to 10	0
4.	Shale fragments, *Illinoian*, red, weak, weathered, in red clayey matrix	5 to 6	0
	Total	15	

ments in a silty matrix. Below it the fragments are thoroughly weathered, have a brick-red color, and lie embedded in a compact, clayey matrix. Here, as near Danville, the lower horizon, which has clearly been subjected to pre-Wisconsin weathering, must be Illinoian in age; and the age of the upper horizon is open to question, but is presumably Wisconsin.

SURFACE FEATURES

Numerous surface features were produced by frost-action. The tops of the hills and mountains were rounded and covered with congelifractate. The slopes were smoothed and lengthened. Wherever only a small quantity of congelifractate was produced on the tops of small, steep-sided hills, the hills were swept bare by congeliturbation and rounded rock outcrops, surrounded by gentle, soil-covered slopes, were exposed. Later surface erosion of the congeliturbate on the slopes led to a concentration of boulders on the surface, particularly in the lines of small parallel channels. In the larger drainageways this boulder concentration led to the development of blockfields. Blockfields also formed on flat surfaces and are composed of large congelifracts frost-riven from the underlying rocks. Blockfields and boulder-strewn slopes were formed during both Wisconsin and Illinoian time. It is sometimes possible to distinguish between these periods of strong frost-action by the amount of weathering of the boulders, as well as by the weathering of the surrounding congeliturbate.

Mountain Tops.

The mountain tops in the periglacial region are smooth and slope gently away from the crest at angles of less than 10 degrees. Bedrock is near the surface and is exposed in many localities. Usually, however, it is covered by a mantle of rock fragments or by a slightly disturbed rubble.

Wherever the profiles of the hills were characterized by a small radius of curvature at the crest and by long slopes, the quantity of congelifractate which was produced was insufficient to bury the hilltops. The process of congeliturbation was, however, capable of removing all comminuted material from the upper part of the slope and, as a result, the top of these hills consists of bare rock outcrops. This is a common characteristic of the hogbacks formed by the Silurian Bloomsburg formation in the neighborhood of Milton (m.134). The occurrence of a similar feature along Conoy Creek (m.51), 2½ miles south southwest of Elizabethtown, is taken as evidence that frost was an effective geomorphic agent in southern Pennsylvania. Here rounded outcrops, of a fanglomerate of the Triassic New Oxford series, composed of angular pebbles, 1 to 2 inches in diameter, of fine-grained, gray limestone and red argillaceous limestone in a calcareous matrix, are exposed as knobs which rise above the valley floor. They are separated from each other and from the alluviated valley by gently sloping, soil-covered surfaces and give the landscape the appearance of one which had once been severely glaciated.

In many places the tops of mountains are covered with rubble. At the crest of Little Mountain (1710 feet above sea level) (fig. 13-R_3, p. 51), 9½ miles southeast of Catawissa (m.143) a road cut on Highway 42, about 20 feet deep, (fig. 22, p. 68) exposes 18 inches to 10 feet of slightly disturbed congeliturbate lying upon Pocono sandstone. Here congelifraction and congeliturbation were effective up to and on the mountain crest. This mountain top was modified and lowered by Pleistocene frost-action. The surface, whose slope gradually increases away from the crest to 22 degrees, is forested and has a surface cover or mantle, 3 to 4 inches thick, of angular pebbles. No sand or silt occurs in the interstices. This mantle is probably the result of selective erosion of the fine-grained particles by surface run-off, which left behind a concentration of the larger pieces.

The upper part of the congeliturbate consists of an accumulation, about 5 feet thick, of small, slightly oxidized, angular, sandstone cob-

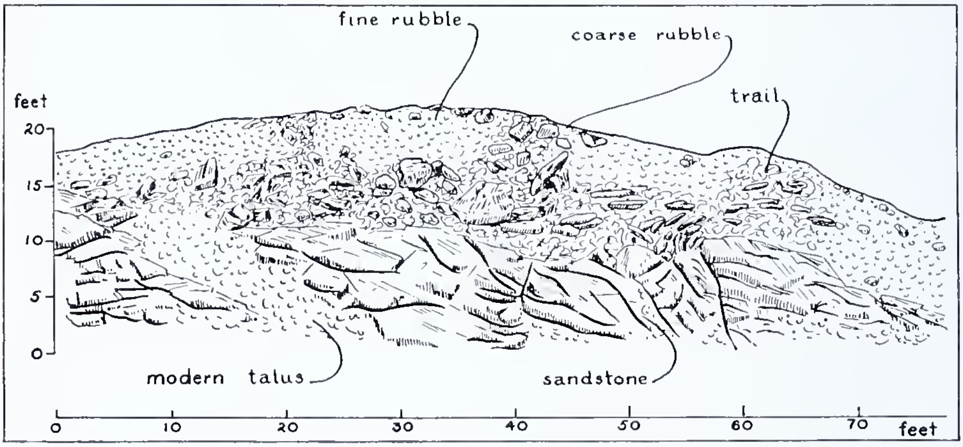

FIGURE 22. Sketch of the relationship between rubble and bed rock in road cut on the crest of Little Mountain.

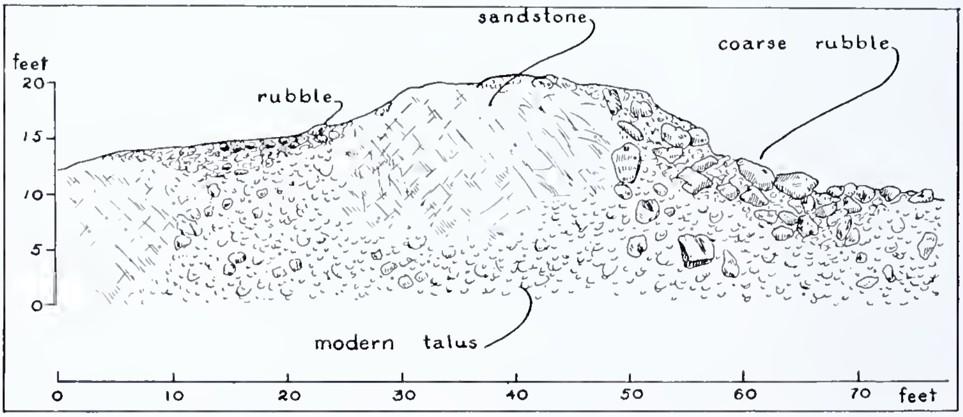

FIGURE 23. Sketch of the relationship between rubble and bed rock in road cut on the crest of Big Mountain.

bles and pebbles. Beneath the crest the fine-grained rubble lies between vertical projections of the coarser, lower layer. Here it has been only slightly disturbed and has not moved far from its parent rock. On the adjacent slope there are signs of increased mixing of the fine-grained rubble with that of the coarser zone and the development of the common type of congeliturbate.

The lower part of the congeliturbate, about 5 feet thick, consists of large, angular, platy boulders and cobblestones in a poorly sorted matrix of silt and sand. The boulders are frequently close to their original position on the sandstone surface. In the rubble at the crest they have been tipped on end and, in places, carried to the surface by congeliturbation. In the thicker rubble 50 feet down the slope, where the congeliturbate has increased in thickness to 10 feet, the boulders are not tilted but are oriented with their broad surfaces parallel to the slope. Here movement parallel to the slope appears to have predominated over the vertical movement caused by frost-heaving. The surface of the sandstone, below this zone, is irregular with 4 to 5 feet of relief, and is shattered to a depth of at least 5 feet.

Another road cut, about 15 feet deep, shown in Figure 23 (p. 68), on Highway 42, on the crest of Big Mountain at 1680 feet above sea level, 11 miles southeast of Catawissa (m.143) (fig. 13-R_4, p. 51), illustrates the effect of congeliturbate in smoothing the topography. Here sandstone bedrock is exposed at the surface, but the highest point is covered by large, angular boulders up to 3 feet in diameter. These boulders cover the south side of the outcrop to a depth of 5 to 6 feet. They are largely free from fine-grained, interstitial material, which has probably been removed by surface run-off. The boulder zone is deepest at the contact between a buff, sandy, coarse-grained congeliturbate and the southern slope of the bedrock. At this place there is a small drainageway which slopes westward. On the northern side of the exposure the rubble has filled a depression about 6 feet deep in the bedrock surface and formed, there, a level terrace. Thus, the mountain crest was rounded and smoothed by filling in depressions as well as by the break-up of projections and the removal of the resulting fragments.

These congeliturbate deposits, on Little and Big Mountains, and the boulders on their surfaces, are only slightly weathered. The soils which are formed on them are white or buff-colored and poorly developed. They show none of the characteristic effects of the pre-Wisconsin climate and must represent only the weathering of post-Olean time. The deposits are, therefore, assumed to be of Wisconsin age.

Boulder-Strewn Slopes.

On those mountains which are mantled with a rubble derived from the massive, resistant quartzite, sandstone or conglomerate formations, such as the Ordovician (Juniata), Silurian (Tuscarora), Mississippian (Pocono), and Pennsylvania (Pottsville) formations, the slopes, which usually vary between 22 and 26 degrees and which tend to flatten toward the foot of the mountain to about 5 degrees, are strewn or even completely covered with large, unoriented boulders.

These boulders which, as was described on pages 67 and 68, tend to be concentrated at the surface, are commonly from 1 to 3 feet in diameter, but may be as large as 8 feet.

The slope of Jacks Mountain near Mapleton (m.163), discussed on page 62, is such a slope (fig. 13-BF$_1$, p. 51). The boulders are scattered over most of the surface, embedded in rubble, and form a layer only 1 or 2 boulders deep. However, at the eastern end of the road cut (fig. 19, p. 62) the finer particles of the rubble are absent and the boulders appear on the barren, treeless surface which slopes at an angle of 29 degrees. The voids between the boulders are open to a depth of about 3 feet, and it is likely that the same process which washed away the fine particles in the rubble and led to the concentration of boulders on the surface, a few feet away, was here more effective and removed all fine particles from between the boulders to this depth. This deposit is not a modern talus brought into place by present-day gravitational processes, for the boulders show no freshly broken corners and the forest is encroaching on the area. These boulders, therefore, reached this position in the past and are a variation in the normal congeliturbate of the mountain slopes.

Both Shade and Blue Mountains, along the Lewistown Narrows (m.129 to 123) (fig. 13-BF$_2$, p. 51), have on their slopes large boulder patches barren of forest. In some places the stability of these boulders is not great, and special precautions must be taken when excavating among them. The voids between the blocks are open for depths of 3 to 8 feet. Below this the voids are filled with sandy congeliturbate. These boulders, which may have been deposited as a

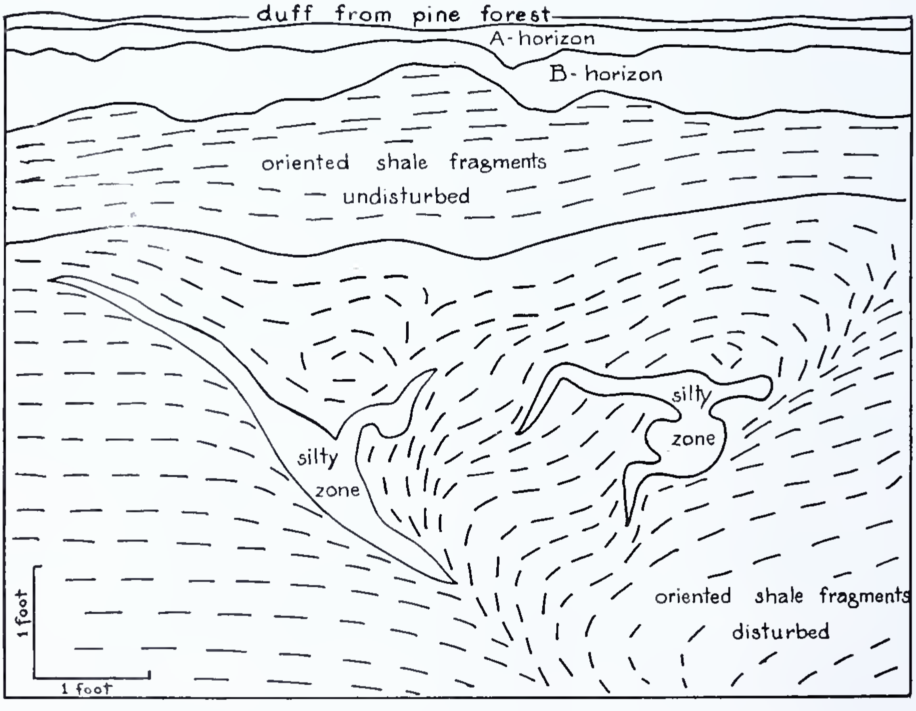

FIGURE 24. Profile of wind gap on Bald Eagle Mountain near Montoursville (m.157) showing the relationship between the rubble slopes and the blockfield in the floor of the gap.

talus, do not appear to be in general movement today, for all of the blocks show the effects of post-Wisconsin weathering and trees are encroaching onto the barren, boulder-strewn surfaces. These barren slopes must be considered as predominantly remnants of past processes which are now much less effective.

The eastern wall of a windgap in Bald Eagle Mountain (see maps, figs. 13-BF$_3$ and 36, pp. 51, 102), 1½ to 2½ miles south of Montoursville (m.157), has, as is shown in Figure 24 (p. 70), a slope which decreases toward its foot from about 25 degrees to about 10 degrees. It is strewn with quartzite boulders, 1 to 8 feet in diameter, but most of the boulders are less than 4 feet wide. These boulders are concentrated in low, parallel ridges, about 100 yards apart, which rise to 3 or 4 feet in height above the adjacent surface and are from 2 to 20 feet wide. They extend down the mountainside parallel to the slope in such a manner as to give it a streaked appearance. The origin of these ridges is a matter for conjecture. Probably they represent abandoned drainageways in which the boulders became concentrated, followed by a small-scale inversion of the topography.

A small outcrop of Tuscarora sandstone occurs 560 feet above the valley floor, at 1700 feet above sea level. It forms a low cliff 10 feet high and 50 feet long. This outcrop represents one source of the boulders and congeliturbate on the slopes below. The other source was the bedrock, on the slope, which is now buried beneath the rubble and which probably never was exposed at the surface. Above the outcrop the slope flattens and the surface is strewn with boulders. Here and there are small, tongue-shaped masses of boulders, illustrated in Figure 25 (p. 71). The surface of these masses has a more gentle gradient than the surrounding slope and, downslope, rises to heights of 3 to 5 feet above it. The lower edge is abruptly terminated by a steeper slope. It appears to be a relic of a mass which once moved as a viscous fluid over the congeliturbate. In this respect it is analogous to the altiplanation terracettes described by Cairnes (1912).

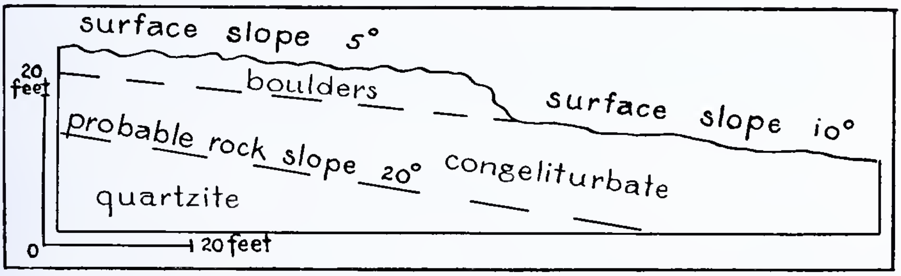

FIGURE 25. Diagram of boulder terrace on Bald Eagle Mountain.

The smooth, congeliturbate-mantled slope on the south flank of Bald Eagle Mountain, similar to that illustrated in Figure 26, (p. 72), extends in an unbroken slope across the band of Silurian rocks and Illinoian till along Black Hole Creek (m.146). The strew of quartzite boulders continues uninterrupted over all of these. This slope, 4 miles west of Montgomery (m.146), is broken by small strike valleys about 50 feet deep. The boulder strew is continuous on both sides of these valleys and was presumably deposited before

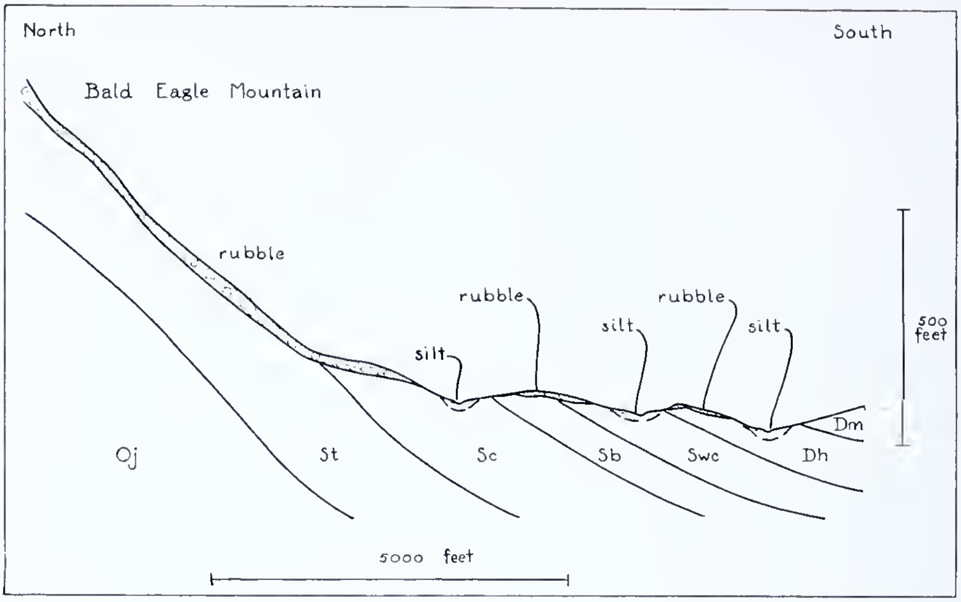

FIGURE 26. Geologic cross-section of south flank of Bald Eagle Moutain near Montgomery (m.145) showing relationship of rubble and silt to underlying bed rock.

the valleys were cut. For these reasons a Late Illinoian age is given to some of the congeliturbate deposits on Bald Eagle Mountain, and a post-Illinoian age to the small strike valleys. Additional congelifraction and congeliturbation took place during Wisconsin time, as is indicated by some slightly weathered deposits on the mountain.

TABLE 33. *Geologic Section in Road Cut in the South Flank of Bald Eagle Mountain, 2½ miles south of Montoursville, Milton, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Boulders, quartzite, sub-angular, weathered, with large open voids . . .	3 to 5	0
2.	Boulders, quartzite, sub-angular, weathered. Voids filled with medium-to coarse-grained, stratified sand	1 to 1½	0
3.	Rubble, buff, coarse, composed of angular boulders, cobbles and pebbles of white quartzite in a tan-colored sandy and silty matrix. To base	3	0
	Total	8	0

Near the bottom of the windgap, illustrated in Figure 24 (p. 70), the boulders which lie on the surface and embedded in the rubble are larger and commonly reach 5 to 8 feet in diameter. A section, presented in Table 33 (p. 72), which was exposed in a road cut on Highway 404, consists of a thin mantle of angular boulders whose corners and edges have been rounded by weathering, underlain by a mass of less weathered boulders with sharp corners. Between the boulders of this lower layer there is a deposit of coarse-grained, alluvial sand. At the base of the cut, beneath these boulder zones, there is a deposit of buff-colored, unsorted, boulder-bearing rubble. The presence of alluvial sand between the boulders and below the zone of open voids supports the hypothesis, presented on page 63, that the fine-grained particles have been washed from between the boulders by surface run-off.

A statistical study of the orientation of 57 surface boulders, which form the surface of a sample area 29 feet by 15 feet on the east slope of the windgap, 100 feet above its floor, showed that, unlike many rubble deposits which still contain their interstitial, fine-grained particles, the boulders do not have a preferred orientation parallel to the slope. However, since they do not lie in a matrix of smaller fragments but upon other boulders, their random orientation is interpreted to be that which was assumed when they were undermined by the washing-out of the fine-grained particles from the voids.

Blockfields

The blockfields are the most spectacular of the periglacial surface features and have attracted special attention (Darwin, 1839; Anderson, 1907; Högbom, 1926; Ver Steeg, 1930; Schott, 1931; Ashley, 1933; Büdel, 1937; and others). The names which have been applied to them are picturesque and fanciful, such as: Head (De La Beche, 1839), Devils Race Course (Hummelstown, Pa., Quadrangle, U. S. G. S., 1892), Stone River (Anderson, 1907), Rock Sea (Felsenmeere, Klemm, 1918), Boulder Sea (Blockmeere, Högbom, 1926), and Boulder Stream (Blockströme, Quiring, 1928). In Pennsylvania they occur in scattered localities where they form barren, treeless surfaces. Boulders 2 to 7 feet in diameter pave these surfaces and all materials smaller than large pebbles are absent. The blockfields range in size from 300 to 1000 feet long and 50 to 500 feet wide, and have gradients of 1 to 5 degrees. The boulders have no preferred orientation and rise to an essentially even altitude in any cross-section at right angles to the gradient of the blockfield. However, there are anastomosing furrows or lines along which the boulder surface is 3 to 5 feet lower than that on either side. Running water is usually found below these furrows, and both the furrows and the absence of orientation of the boulders are probably the result of sub-surface erosion by this water.

A blockfield, which exhibits all of the characteristic features, lies along the bottom of the windgap in Bald Eagle Mountain, see Figure 24 (p. 70), at an elevation of 1140 feet above sea level. It is composed entirely of quartzite boulders and cobbles derived from the Juniata formation, which underlies the area and part of the adjacent mountainside, and the Tuscarora formation which forms the higher slopes. They range from 6 inches to 5 feet in diameter. A statistical analysis of the orientation of 50 of these boulders, found within an area of 150 square feet, shows that they have no preferred orientation and their positions must, like those of the boulders on the adjacent slope, described on page 72, be explained as the result of subsidence following the washing-out of the interstitial material.

In the upper 5 feet, the voids between the boulders are open. Below, they contain sorted, medium- to coarse-grained sand similar to that described, from the adjacent slope, on page 72. These boulders, like those on the adjacent mountain slopes, are weathered. The surface has a soft, weathered crust ⅛ inch thick and is covered with pits up to 3 or 4 inches deep. The edges and corners of the blocks are rounded. Here and there a sharp, angular corner and a fresh chip, 3 to 5 inches across, may be found. These chips are the product of modern frost-splitting which, like modern chemical weathering, is serving to break down rather than develop the blockfield.

The blockfield extends for about half a mile in a south 12 degrees east direction, at a slope of 2 degrees south. It has a ridge-and-furrow topography in which two longitudinal furrows about 3 feet deep and 5 to 7 feet wide, one on each side of the field, predominate. On the outer side of these the slope increases rapidly to 25 degrees, and the blockfield merges with the adjacent slope. This slope is boulder-strewn, with parallel, boulder ridges, described on page 71, and underlain by 6 to 8 feet of buff-colored congeliturbate. The surface is forested with beech, oak and rhododendron, with patches of pine and hemlock, and is apparently quite stable. North of the blockfield the valley floor is a flat, tree-covered, poorly drained, boulder-strewn surface, on which the surface drainage was inadequate to wash away the soil. Toward its southern end the blockfield narrows, as the slope increases, and merges into a tree-covered, bouldery creek bed. The weathered, sub-angular appearance of the boulders indicates that they have been exposed here for a long time. Since the blockfield merges with the adjacent mass of rubble, it is assumed to be of the same post-Illinoian age.

One mile northeast of Laporte and 26 miles northeast of Muncy (m.150), on the hillside along Highway 220, there is a small blockfield (fig. 13-BF$_4$, p. 51), 300 feet long and 50 feet wide, which slopes at 1 degree toward north 70 degrees west. It is composed of sharp, angular boulders of Pocono sandstone which are weathered on the surface and show brown liesegangs rings to a depth of 1½ to 2 inches. Its surface is furrowed to a depth of 1 to 2 feet, and water was found at a depth of 3 feet. The eastern end of the blockfield merges into a flat, forested, boulder-strewn surface which is covered by leaves and moss and which is crossed by an anastomosing series of furrows and depressions about a foot deep. It is a covered part of the blockfield, which, together with the barren blockfield, extends over an area about 1000 feet long and 150 feet wide. Downstream the blockfield narrows and grades into a forest-covered, bouldery gully.

This blockfield lies 10 miles behind the Olean "terminal moraine" on a glaciated surface and, therefore, is not older than Olean in age. It is not composed of glacially transported boulders, but is uniformly made up of frost-riven boulders derived from the underlying rock. There is no indication that these boulders have moved far from their parent outcrop.

There are numerous other blockfields in Pennsylvania, outside of the Susquehanna Valley, which are similar in every respect to those described here. Those blockfields which are known to the writer are shown on the map in Figure 13 (p. 51). They occur both within and beyond the glaciated area. Some are post-Illinoian and others post-Olean in age. All are features of the Pleistocene epoch. They were formed by congelifraction and movement to the valley bottoms by congeliturbation, or by congelifraction alone, on poorly drained, relatively flat surfaces. They are barren and treeless because, at some later time, presumably before plants became well established, the fines were washed out from among the boulders.

TERRACES OF THE NORTH BRANCH, SUSQUEHANNA RIVER

DESCRIPTION OF VALLEY

The North Branch of the Susquehanna River was studied from Waverly, New York (m.286), near its junction with the Chemung River (m.278), southward for 163 miles to its junction with the West Branch (m.123). For 21 miles, from Waverly to Towanda (m.265), the river flows southward surrounded by rolling hills through a broad, straight valley, which narrows toward the south. The grade of the stream is broken by a nickpoint, shown in Figure 27 (p. 75), at the junction with the Chemung River at an altitude of 740 feet, and again at Towanda at 700 feet.

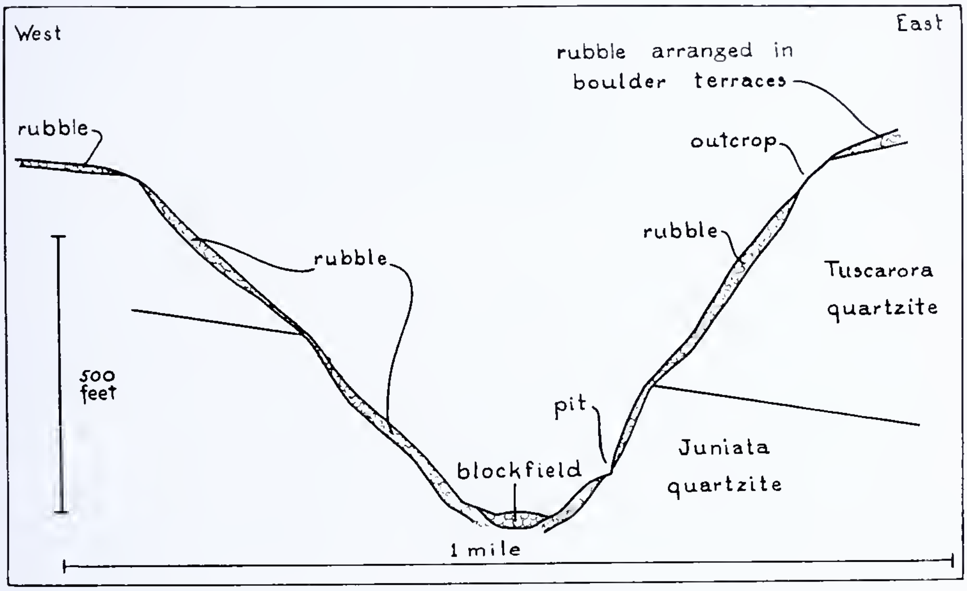

FIGURE 27. Profile of grades of the several terrace systems on the North Branch, Susquehanna River.

At East Towanda (m.263) the stream course turns southeastward and enters the more rugged upland of the Appalachian Plateau, through which it flows in a series of eleven meanders incised in a narrow, steep-sided valley whose walls are about 500 feet high.

Below Wyalusing (m.247) the valley of the inner gorge widens downstream, and a rock bench about 125 feet above the river begins to appear. First described by White (1883), it appears to correlate with the rock terrace at 760 feet above sea level in the Lackawanna Valley described by Itter (1938). Near Falls (m.205), 3 miles above the Allegheny Front, there is a break in the grade of the stream at an altitude of 580 feet. The stream then flows southward through two bends or imperfect meanders, which are incised in a zone of gently rolling hills, whose summits reach a generally accordant altitude of 1300 to 1400 feet, thence through Bald Mountain to the Wyoming Valley and the junction with the Lackawanna River.

The Wyoming Valley has been well described by White (1883), Darton (1914), Itter (1938) and others. It is a broad valley surrounded by mountains and composed of two zones. One zone consists of gravel and sand terraces about 1½ miles wide along the right bank of the river. It is underlain by the buried valley, 100 to 150 feet below the river level, described by Hill (1884) and Darton (1914). The other zone, 2 miles wide along the left bank, is occupied by hills, at about 800 feet above sea level.

The grade of the river is broken near Plymouth (m.181) by a nickpoint at 520 feet above sea level, which appears to represent the headward advance of a riffle from the narrows at Nanticoke (m.177), 3 miles below. No other nickpoint occurs on the North Branch downstream from this point. Except where they may be related to the confluence of two major streams, as at the junction with the Chemung River, the nickpoints on this branch occur about 3 miles upstream from a structural contact.

At Nanticoke the river turns its course almost at right angles to cross the axis of Bald Mountain, thence flows west southwestward for 8 miles through a narrow valley bounded on each side by the steep walls of the mountain. At Shickshinny (m.168) it turns abruptly southward, crosses Penobscot Mountain and enters the broad valley through which it flows for most of the remainder of its course. This valley is composed of an alluvial zone, including the river, about a mile wide, and two zones of hills: one whose summits reach 720 to 800 feet above sea level, and another whose summits reach 1000 to 1100 feet above sea level. The northern side of the valley is bounded by Lee Mountain and its structural extension, Knob Mountain, and the southern side by Nescopeck Mountain. These mountains are 1500 to 1800 feet above sea level.

Near Bloomsburg (m.144) the river leaves this valley and turns abruptly southward into the upper hill zone. It follows this course for about a mile, then turns westward, essentially parallel to the valley, and rejoins it at Danville (m.134), 10 miles below. One may speculate concerning the origin of this apparently deserted part of the valley and consider why the Susquehanna does not now flow in it. The deserted valley contains Illinoian till and kame gravels. The high point is about 610 feet above sea level, or at the Harrisburg level of Fridley (1929). It is distinctly above the grade line of the Illinoian outwash terraces. Therefore, if the valley at this point was once occupied by the Susquehanna, the river became diverted prior to Illinoian time. If the level of the low hills, with which the valley appears to correlate, represents either the Harrisburg or Somerville erosion surface, one must suppose that a diversion occurred during the interval between the formation of the partial peneplain and the time of advance of the Illinoian ice. The diversion may have been an auto-piracy by Catawissa Creek and another, but hypothetical, tributary.

From Danville, for 10 miles to the junction with the West Branch, the river flows westsouthwestward, crossing the strike of the rocks at a low angle. The valley, here, has an alluvial plain on the north bank, ¼ to ½ mile wide, and is flanked on either side by hills which rise sharply from 850 to 900 feet above sea level.

TERRACES

General Statement.

Along the North Branch of the Susquehanna River there are numerous remnants of the valley train of the Valley Heads, Binghamton and Olean sub-stages. At their outer edges these remnants, which now form terraces, are, respectively, about 25±5 feet, 40±10 feet, and 65±10 feet above the river. They are flanked, in many places, by kame terraces of Binghamton or Olean age. Below the Valley Heads terrace there is a still lower terrace 15±5 feet above the river. It is commonly covered by modern floods and is mantled with a veneer of Recent sediments, but, as is explained on page 79, it is presumed to be essentially a climatic terrace of Mankato age.

The height of the terraces of any sub-stage varies both along the course of the river and with distance from the centerline of the river. The variation is not great and rarely exceeds the error inherent in measurements made by pace and hand level. Along the river, between Wysox (m.261) and West Pittston (m.192), the terraces are generally higher than those of the same age along other parts of the river. The longitudinal profile of the terraces, (fig. 27, p. 75) is more closely parallel to the longitudinal profile of the modern flood crests such as that of the flood of March, 1936 (fig. 3, p. 8) than to the profile of the present low-water stage. It may, therefore, be presumed that the grade of the gravel fill at any stage, and thence the height of the terraces, was determined by the flood grade. The similarity of flood grades at the present and in the past is in part due to the restriction of the valley walls. It is also due to similarity of hydrologic conditions producing floods, as discussed on page 9.

The terraces, which are chiefly preserved on the inside of bends in the river, slope gently, at an angle of about 1 degree, toward the river. This feature may be due in part to the accumulation of later deposits on the terrace surface and in part to erosion of the outer edge after the terrace was deposited. There may also have been an initial slope of the terrace surface toward the channel of the time. Such an initial slope might be produced if the surface were formed by floods which covered the entire terrace simultaneously, instead of by the lateral shifting of deposits by meandering of braided streams. Hence it seems likely that the outwash plains on this river were formed by floods which covered the valley floor from wall to wall and were not built up by the overbank flow of occasional floods. This type of flooding is attributed to the glacial conditions that existed, as further discussed on page 78.

If the elevations of all terrace remnants be reduced, at a rate of 1 degree, to the centerline of the present stream, most local differences in height disappear and fairly constant heights for any sub-stage are obtained. On the North Branch these heights are: for the Mankato terrace, 9 feet; Valley Heads terrace, 15 feet; Binghamton terrace, 30 feet; and Olean terrace, 45 feet. This operation, previously described on page 11, serves to smooth the longitudinal profile of the terraces, but does not alter their interpretation or correlation. In most instances the difference between the observed terrace height and the river was less than the error of observation. All of the terrace profiles illustrated here were obtained by projecting the outer edge of the terrace horizontally to the centerline of the river.

The surface of most of the terraces has been modified. There is commonly a veneer of pebbly, structureless silt over the outwash gravels. In most instances this silt is probably loess. The inner edges of the terraces are mantled with slopewash, slumped material from the next higher terrace and rubble from the mountainside, so that abrupt contacts between the terraces are rare. The outer edges of the terraces are usually eroded and rounded. In some instances this modification has been so great that a terrace is represented only by a break in slope of the valley walls at the level at which the floods of that sub-stage must have flowed. Such modification (fig. 28, p. 78) has been most effective on the Binghamton and Olean terraces, and is relatively slight on the younger terraces.

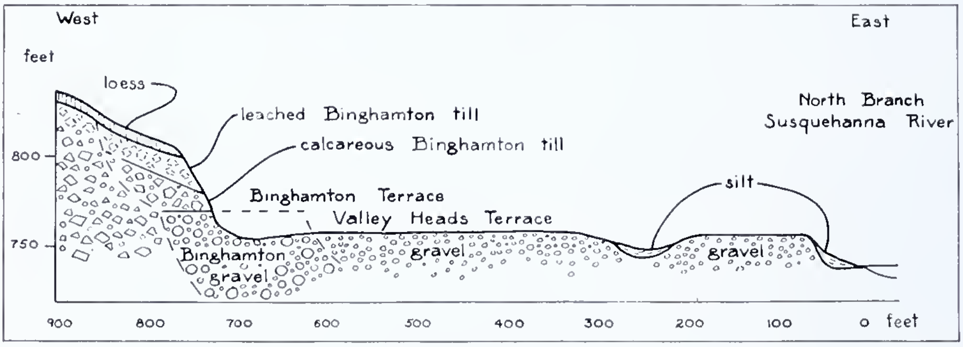

FIGURE 28. Cross-section of right bank of North Branch, Susquehanna River at Greenes Landing (m.278) showing terraces.

For these reasons the observed height of any terrace is subject to an error which may be as great as 30 per cent, and it is necessary to support any correlation of terraces by additional evidence. Along the North Branch it is possible not only to distinguish differences in weathering on terraces of different sub-stages, as described on pages 30 to 47, but also to recognize differences in the composition of the different valley trains (Table 3, p. 18).

Composition.

The lithologic composition of the gravel in the valley train is dependent upon the rate of mixing of the gravel derived from the glacial ice with gravels from tributary streams and the valley walls, and upon the varying rates of disintegration of the different kinds of pebbles as they were carried downstream. The gravel brought into the drainage system by the Chemung River is different from that carried by the North Branch of the Susquehanna River. The gravel of the Chemung River contains a higher proportion of red sandstone, chert, granite and gneiss pebbles. In the Valley Heads terrace the mixing of the two gravels becomes evident within 20 miles of the junction of the Chemung and North Branch (m.279). If 60 per cent of Chemung gravel were to be mixed with 40 per cent of North Branch gravel, the resulting composition would be similar to that of the Valley Heads terrace at Wysox (m.261), 18 miles downstream from the junction. In the Binghamton terrace the relationship of glacial gravels to previously deposited valley fill is shown. These gravels, even though they moved across the Appalachian Plateau through a steep-sided valley which was filled with Olean deposits and whose walls were mantled with Olean till, retained their distinctive composition for at least 80 miles. The retention of distinctive features in glacial outwash gravel indicates that mixing with the materials deposited or brought in by small side-streams was slight. Presumably the river was so heavily loaded with glacially derived sand and gravel from the north that it accomplished little or no lateral erosion. The valley train gravel merely filled the channel cut during the preceding interstadial period, and, as it increased in thickness, covered without eroding the previously deposited gravels that stood below its final level. However, the rate of mixing, of the order of 0.2 to 0.5 per cent per mile, was sufficiently great so that, within 200 miles, the original composition of the outwash is completely masked and the original glacial source becomes difficult to recognize. At the distance of 200 miles from the ice front most of the material in a valley train is not actually derived from melting ice, but is washed from hillsides and transported by spring and summer floods of streams in the periglacial zone. This change in the composition of the valley train gravels was recognized by Shaw and others (1914), for they placed the downstream limit of terrace soils derived from glacial outwash near Catawissa (m.143).

The pebbles in the gravel have a variable resistance to stream abrasion, depending upon their lithology. In general, quartzite and chert are the most resistant and tend to increase in relative proportion downstream. This relationship is shown in Table 34, (p. 79) by pebble counts in the Valley Heads and Binghamton terraces. The other lithologic types decrease in proportion, in the order of increasing rate of wear: granite and gneiss, blue limestone, gray sandstone and siltstone, red sandstone and siltstone, and shale. As limestone pebbles form a nearly constant proportion in any one terrace and, above the entrance of the Lackawanna River (m.193), are always present, the proportion of limestone pebbles can be used as an index for the identification of the deposit. However, because of the heavy admixture of sandstone pebbles from this river, the limestone pebbles become too small a proportion to be significant in the lower portion of the North Branch.

TABLE 34. *Relative Resistance of Pebbles to Stream Abrasion.*

MATERIAL	AVERAGE RATE OF DECREASE IN PERCENTAGE PER MILE	RATIO
Quartzite	0.005	1.0
Granite and Gneiss	0.022	4.4
Chert	0.032	6.4
Gray Sandstone	0.194	38.8
Red Sandstone	0.238	47.6

Mankato Terraces.

The lowest terraces along the North Branch of the Susquehanna River lie, at the outer edge, 15±5 feet above the river. They are commonly found on islands in the river, or as the outermost of a flight of terraces about 100 feet below the Valley Heads terraces (fig. 29, p. 80). Their surface is covered with a veneer of silt or fine sand deposited by modern floods. Upstream from the Wyoming Basin (m.193 to 177) the surface deposit consists of gray or black silt to medium-grained sand, derived in part from the waste of coal mines. Modern floods overflow this terrace on an average of about once a year. For this reason what is in this paper considered a terrace has been previously referred to as the floodplain (White, 1883) or the "first bottom" (Hendrickson and others, 1929). There is no indication that the river is now building or modifying the Mankato terrace beyond the slow deposition of fine alluvium. In many places the terrace remnant exceeds 500 feet in width and in a few instances this width is greater than 1000 feet. This considerable breadth, the relatively constant height of the remnants above the river, their occasional occurrence above the modern flood level, and the occurrence of gravel which is not now being deposited on the floodplain (shown in Tables 35, 41, 44 and 46, pp. 80 to 122) all indicate that these terraces are not the products of the present stream alone. They are, therefore, thought to be, in part, Pleistocene in age.

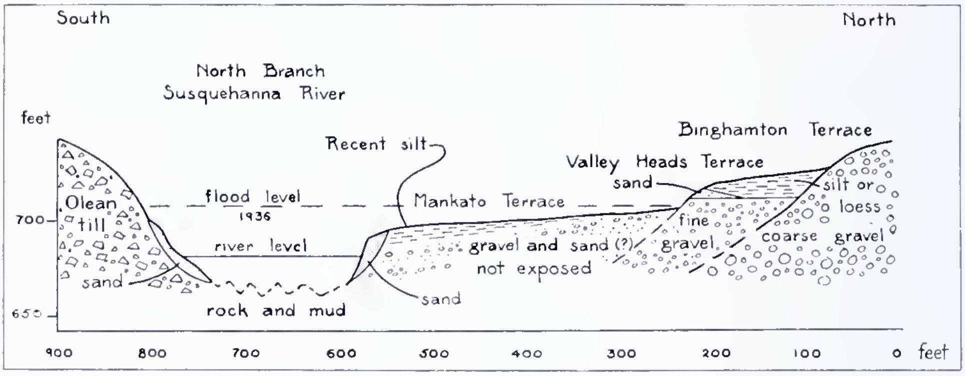

FIGURE 29. Cross-section of valley of North Branch, Susquehanna River at Wysox (m.261) showing terraces.

Because this terrace lies below the Valley Heads terrace, it must have been formed after the Valley Heads sub-stage. The gravel which it contains is taken to indicate the action of more heavily loaded floods than now occur, or than there is reason to believe occurred during any of the Pleistocene interstadial periods. The Mankato ice sheet did not reach far enough south to contribute outwash to the Susquehanna. Nevertheless, the climate of the region must have been affected and consequently this terrace is presumed to be a periglacial terrace related to the last or Mankato sub-stage.

The outer edge of the Mankato terrace is usually steep, but in many localities its erosional face is plastered with modern sand deposits in the form of terracettes. These terracettes range from 10 to 30 feet in width and occur at various elevations up to 12 feet above the river. They are the result of scour of the terrace front during a rising flood, and backfill during the receding stage.

Valley Heads Terraces.

Above the Mankato terraces, about 20 to 30 feet above the river, are terraces, sometimes called the "second bottom" or "high bottom," composed of well sorted, medium- to fine-grained valley train gravel (fig. 29, p. 80). They occur at a lower level than do the terraces of the Binghamton sub-stage and must, therefore, be younger than Binghamton and older than Mankato. The gravels in these terraces may be identified, near the New York State line, on the basis of their weathering and leaching, described on page 38; of their characteristic composition, Table 3 (p. 18); and of the elevation of the terraces. The Valley Heads gravel contains a higher proportion of blue limestone pebbles, has a shallower depth of leaching and a shallower soil profile, than do any of the gravels of the earlier and higher terraces.

The terraces of the Valley Heads sub-stage are commonly narrow and poorly developed. They are not continuous along the river for any great distance. North of the Appalachian Plateau they occur at heights of from 15 to 25 feet, or about 20 to 30 feet below the Binghamton terraces. Within the Appalachian Plateau the Valley Heads terraces, where found, are 25 to 30 feet above the river. Along this part of the river, and downstream from it, there are few exposures of the materials in these terraces. The identification of the Valley Heads terraces as remnants of a once continuous valley train was made on the basis of the relationship of these terraces to the other terraces in the flight and of their general position 20 to 30 feet above the river level. These facts do not indicate that a lesser outwash drained from the Valley Heads ice. The valley train of this sub-stage, like that of the earlier glaciations, was apparently concentrated near the terminal moraine at Spencer Lake and north of Elmira in New York State and, therefore, lies outside of the region considered in this paper.

Binghamton Terraces.

The Binghamton terraces are the best preserved of the glacial outwash terraces along the North Branch. Along most of this branch the terraces of Binghamton age may be recognized by the gravel deposits which they contain. The gravels, illustrated in Tables 3 and 6, (pp. 13 and 20), are similar in lithologic composition and degree of weathering to the kame gravel and till deposits near Greenes Landing (m.278), and are distinct from deposits of greater or lesser age. The terraces were apparently graded to the channel of a river which flowed about 30 feet above the present stream grade. The terraces begin at heights of 30 to 50 feet above the river, depending upon their distance from the river and the part of the river along which they lie. The average height is 35 feet. In general, the greater the distance from the river at which the terrace edge is found, the greater is its height.

The terraces along that part of the river which crosses the Appalachian Plateau are slightly higher than those either upstream or downstream and are slightly higher than the average. The terraces, here, range between 35 and 50 feet in height, with an average height of 43 feet. This local increase in height may mean that this part of the valley, which is narrower and more tortuous than the rest, caused a local decrease in flood velocity and led to higher floods, such as are observed today, and was, therefore, more readily filled up with gravel; or that there has been a very slight post-glacial deformation of the earth's crust, here, possibly related to the isostatic effects of the melting of the ice.

One might expect the effects of crustal deformation, in a valley with so steep a gradient as that of the Susquehanna River, to be imperceptible, whether that deformation be caused by relatively simple southward tilting of the earth's surface, such as was described by Taylor (Leverett and Taylor, 1915), or by a process involving the formation of a peripheral bulge such as was presented by Daly (1934). The projection of the southernmost or Whittlesey Hinge Line, shown by Taylor, extends across Pennsylvania through the Appalachian Plateau and presumably crosses the Susquehanna River north of Pittston (m.192). Deformation along this axis would have steepened the southward gradient of the terraces. However, as may be seen in Figure 27, (p. 75), there is no recognizable steepening of the river or of any of the terraces at this point. There is no divergence in the slope of the terrace grade lines, one from another. If such tilting occurred its effects must, therefore, have been obscured by local conditions. According to the concepts of Daly, the kame terraces immediately upstream from the zone of no deformation would, after deglaciation, be steepened by uplift. Outwash might be thicker in the zone between the glacial ice and the crest of the peripheral bulge. On the other hand, the effects of the peripheral bulge would be small, but its subsidence might cause the terraces to assume a slightly concave-upward profile. No evidence of a peripheral bulge was found (fig. 27, p. 75). The steep slope of the frontal kames, as was demonstrated on page 25, may also be explained without assuming crustal deformation. Conclusive evidence of late-glacial or post-glacial deformation, as inferred from the aforementioned hypothesis, has not been found in the Susquehanna Valley.

There is a general tendency for the Binghamton terraces to decrease in height downstream from 40 feet near the limits of the Binghamton ice, and 37 feet in the Wyoming valley, to about 25 feet at Northumberland (m.123). This decrease in height may be due to a decrease in the height of the Binghamton floods and, as discussed by Lewis (1936), to a downstream decrease in the quantity of gravel in transit. The downstream decrease in the height of the flood crest is a common attribute of glacial outwash streams, see page 9, for the floodwaters of such streams are commonly derived from a single point and there is little addition to the flow by tributary streams of the periglacial region. Throughout their course, across the periglacial region, the glacial meltwaters flowed in a channel filled with sand and gravel. As these waters progressed toward the sea more and more water must have been absorbed by the valley fill and therefore lost to the flood. The effects of channel storage caused a progressive decrease in the height of the flood crest as it moved downstream.

The floods of the Binghamton sub-stage did not differ in height from modern floods, if one assumes that the channel was built up with gravel, for within the glaciated region the Binghamton terraces

TABLE 15. *Terraces of the North Branch, Susquehanna River*

All measurements by pace and hand level unless otherwise indicated

Miles [illegible]	Place	Bank	Terrace	Height	Width	Remarks
[illegible]	[illegible] State Line	right	[illegible]		[illegible]	[illegible]
	[illegible]	[illegible]	Mankato	[illegible]	[illegible]	[illegible]
			Valley Heads		[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Meshoppen	left	Valley Heads	30	150	Chemung gravels. Kame
			Binghamton	[illegible]	1200	[illegible]
[illegible]	Big Lake	left	Valley Heads	35	120	[illegible]
			Olean	[illegible]	[illegible]	Chemung gravels. Kame
			Olean Upper kame terrace	90	[illegible]	Coarse gravel. [illegible]
[illegible]	Vosburg	right	Mankato	15	10	
			Valley Heads	33	260	[illegible]
			Binghamton	45	150	[illegible]
			Olean	63	[illegible]	[illegible]
			Olean Lower kame terrace	85	460	[illegible]
[illegible]	Tunkhannock	left	Valley Heads	27	300	[illegible]
			Binghamton	45	240	[illegible]
			Olean	[illegible]	[illegible]	[illegible]
			Olean Lower kame terrace	65	[illegible]	[illegible] Chemung [illegible] kame
227	[illegible]	left	Valley Heads	20	[illegible]	White described [illegible] terraces from South [illegible]
[illegible]	2 miles west of Falls	left	Valley Heads	21	80	
			Binghamton	31	[illegible]	This is probably [illegible] terrace of White [illegible] South Eaton. Chemung gravels. Kame
			Olean 2nd kame terrace	115	[illegible]	This is probably the [illegible] terrace of White. Chemung [illegible] kame
[illegible]	Falls	right	Mankato	15	250	Not covered by 1936 flood. Tioga [illegible] kame
			Valley Heads	21	180	This is probably the [illegible] of White. Tioga [illegible] kame
[illegible]	Keelers [illegible]	left	Mankato	15	40	Not covered by 1936 flood. Tioga [illegible]
			Valley Heads	21	101	Tioga [illegible] kame
			Binghamton	[illegible]	100	Tioga [illegible]
[illegible]	West [illegible]	right	Recent	[illegible]	18	Sand
			Recent	[illegible]	15	Sand
			Valley Heads	[illegible]	100	[illegible]
192	West Pittston	right	Recent	[illegible]	20	
			Recent	[illegible]	15	
			Valley Heads	[illegible]	1100	
			Binghamton	[illegible]	2900	
[illegible]	Forty Fort	right	Binghamton	[illegible]	2100	
[illegible]	Wilkes Barre	left	Valley Heads	[illegible]		U. S. Army Corps Eng. profile
[illegible]	Kingston	right	Recent	1	200	U. S. Army Corps Eng. profile
			Recent	6	4250	
			Valley Heads	[illegible]	[illegible]	
[illegible]	Hunlock Creek	right	Mankato	[illegible]	420	U. S. Army Corps Eng. profile. Slope toward river [illegible]
[illegible]	Hicks Ferry	right	Mankato	11	[illegible]	
			Binghamton	[illegible]	[illegible]	
			Olean	[illegible]	100	
			Olean Lower kame terrace	[illegible]	300	
[illegible]	1 mile E. of Beach Haven	left	Mankato	11	120	
			Binghamton	11	100	1st terrace of White (1883)
			Olean	61	250	Probably 2nd terrace of White
			Olean Lower kame terrace	85	120	Coarse gravel
			Olean 2nd kame terrace	110	400	12 ft. outwash gravel exposed. Probably 3rd terrace of White
[illegible]	Nescopeck	left	Binghamton	11	650	Kame gravel overlain by outwash
[illegible]	Berwick	right	Olean Lower kame terrace	65	1700	Probably the 100 ft. terrace of White and the 120-foot terrace of Leverett
[illegible]	1 mile E. of Briar Creek	right	Recent	12	32	Silt and sand
			Mankato	15	121	Medium gravel overlain by sand
			Binghamton	31	125	Coarse gravel
			Olean	40	1250	
			Olean	65	200	Frontal Kame from Olean Lower Kame terrace.
[illegible]	Mifflinville	left	Binghamton	26	350	Gravel. White described 10-foot and 21-foot terraces here and Leverett described a 65-foot terrace here. They are Olean frontal Kame and Olean valley train terraces respectively
[illegible]	[illegible] Lime Ridge	right	Binghamton	[illegible]	700	Gravel. Chemung and others
[illegible]	[illegible] miles [illegible] of Espy	right	Binghamton	21	1200	U. S. Army Corps Eng. profile
[illegible]	Espy	right	Binghamton	30	300	
[illegible]	Rupert	right	Recent	7	10	
			Valley Heads	18	450	[illegible] 25-foot terrace of White. White described [illegible]
[illegible]	[illegible]	left	Valley Heads	[illegible]	150	U. S. Army Corps Eng. profile
[illegible]	[illegible]	left	Valley Heads	11	100	
			Binghamton	30	200	Wheeling and others
			Olean	11	[illegible]	Wheeling and others
	[illegible]	right	Binghamton	21		Wheeling and others
			[illegible]	31		Wheeling and others
			[illegible]	60		

have a relief which is about equal to the rise of modern floods. The floods differed in the quantity of the bed-load, and the size of the particles, which were transported. The bed-load of floods in the Binghamton sub-stage was both greater in volume and coarser-grained.

The gravel deposits in the Binghamton terraces near the source of the floodwaters differ, in the amount of sorting and origin of the pebbles, from those in more remote terraces in the periglacial region. Within 90 miles of the limits of the Binghamton ice, the gravel deposits are clean, well sorted, and relatively free from silt. The deposits in the last 20 or 30 miles, however, appear to contain increased quantities of sand in the voids between the pebbles. Throughout this distance the pebbles are characteristic of a Binghamton deposit and may be traced by their lithology (Table 3, p. 18) to the Binghamton till deposits upstream.

Further downstream, beyond the limits of the Olean ice and about 125 miles from the limits of the Binghamton ice, the gravels in the Binghamton terraces consist of poorly sorted, medium- to coarse-grained gravel in a matrix of silty, medium- to fine-grained sand. The lithology of the pebbles is no longer characteristic of the Binghamton deposits. The gravel resembles that of a climatic terrace of the periglacial region more closely than it does an outwash deposit near the source of the floodwaters.

The gradual change in the lithology of the pebbles and sorting of the gravels, from well sorted gravels with characteristic lithology to poorly sorted gravels derived chiefly from local sources, indicates that not only were the glacially derived gravels replaced by gravels of local origin, as the gravel sheet moved downstream, but that the floods on the river were diminished in height and sharpness of the crest. The sand and silt washed out from the gravels near their source were deposited with the more distant gravels. In essence the Binghamton valley train terraces grade downstream into corresponding periglacial, climatic terraces.

The Binghamton terraces are commonly modified, to a greater degree than the younger terraces, by the accumulation of rubble and slopewash and by the dissection by small streams. The outer edge is often rounded and the slope of the surface greater than that which one would expect to have been formed by the floods of the Susquehanna. This modification is most noticeable near the Binghamton ice limits and appears to decrease downstream.

Olean Terraces.

Olean outwash terraces, the highest outwash terraces along most of the North Branch, first appear near Asylum (m.253). They emerge, downstream from the frontal kame terraces which connect the Binghamton marginal kame terraces with the valley train terraces of Binghamton outwash. The gravel deposits of Olean age are easily recognized, for the leaching and weathering of these deposits have been carried on to a distinctly greater extent than in the terrace gravels of lesser age. The lithologic composition of the gravel is also distinct, for, as is indicated in Table 3, (p. 18), the Olean glacial deposits contain fewer pebbles foreign to the region than do the younger deposits. Within the area once covered by Olean ice, these terraces have gravels whose composition closely parallels that of the adjacent till. Beyond the limits of the Olean glaciation, and as far as the junction with the West Branch, the valley train gravels have lithologic characteristics similar to those of the gravels deposited near the ice margin.

Within the region glaciated by Olean ice, the Olean terraces vary in height from 55 to 85 feet, with an average height of about 68 feet. Like the Binghamton and Valley Heads terraces, the Olean terraces rise slightly in the vicinity of Wyalusing (m.245). This rise is also probably due to a decrease in the rate of flow of floodwaters in this part of the river; for, as is true of the younger terraces, the Olean terraces fall to a lower level near the nickpoint at Falls (m.205).

Below the Olean glacial boundary at Berwick (m. 159) the terraces gradually decrease in elevation to about 55 feet at the junction with the West Branch. Presumably, as will be shown later (p. 110), they drop to lower levels on the main part of the Susquehanna as a result of decreasing flood heights and decreasing quantity of bed-load, in a similar manner to that of the Binghamton terraces; but such a drop, if present, is obscured by the effects of nickpoints in the stream grade.

The Olean terraces usually do not have a sharp, well defined, outer edge, but have, instead, a rounded, modified slope. The surface of the terrace is rarely that of the original depositional plain for, in addition to deposits of rubble and slopewash, there is commonly a mantle of pebbly silt, or loess.

Illinoian Terraces.

Deposits of Illinoian gravel are easily distinguished from later gravels by their red or reddish-brown color. They occur in scattered and isolated patches along the North Branch between Lime Ridge (m.151) and Northumberland (m.123). Most of them, however, are ice-contact deposits and lie at high levels, 140 to 180 feet above the river. Terraces of Illinoian valley train gravel occur along the North Branch between Bloomsburg (m.146) and Northumberland, where they lie about 75 feet above the river.

Along the right bank of the river, 3 to 6 miles below Danville (m.134), gravels with characteristic Illinoian weathering lie about 30 feet above the river. This is below the level of the Olean terraces, and it must be supposed that the surface of these gravels was modified by floodwaters during the Olean sub-stage. The occurrence of Illinoian gravel at so low an elevation is taken to indicate that the river, here, has not lowered its bed significantly since Illinoian time.

At Northumberland (m.123), at the junction with the West Branch, Illinoian gravel lies on a terrace 80 feet above the river. This terrace, described by White (1883) as broad, ¼-mile-wide bench, correlates with the Illinoian terrace on the West Branch and main Susquehanna River. This terrace, further discussed on page 112, probably consists of a gravel deposit lying upon a rock bench.

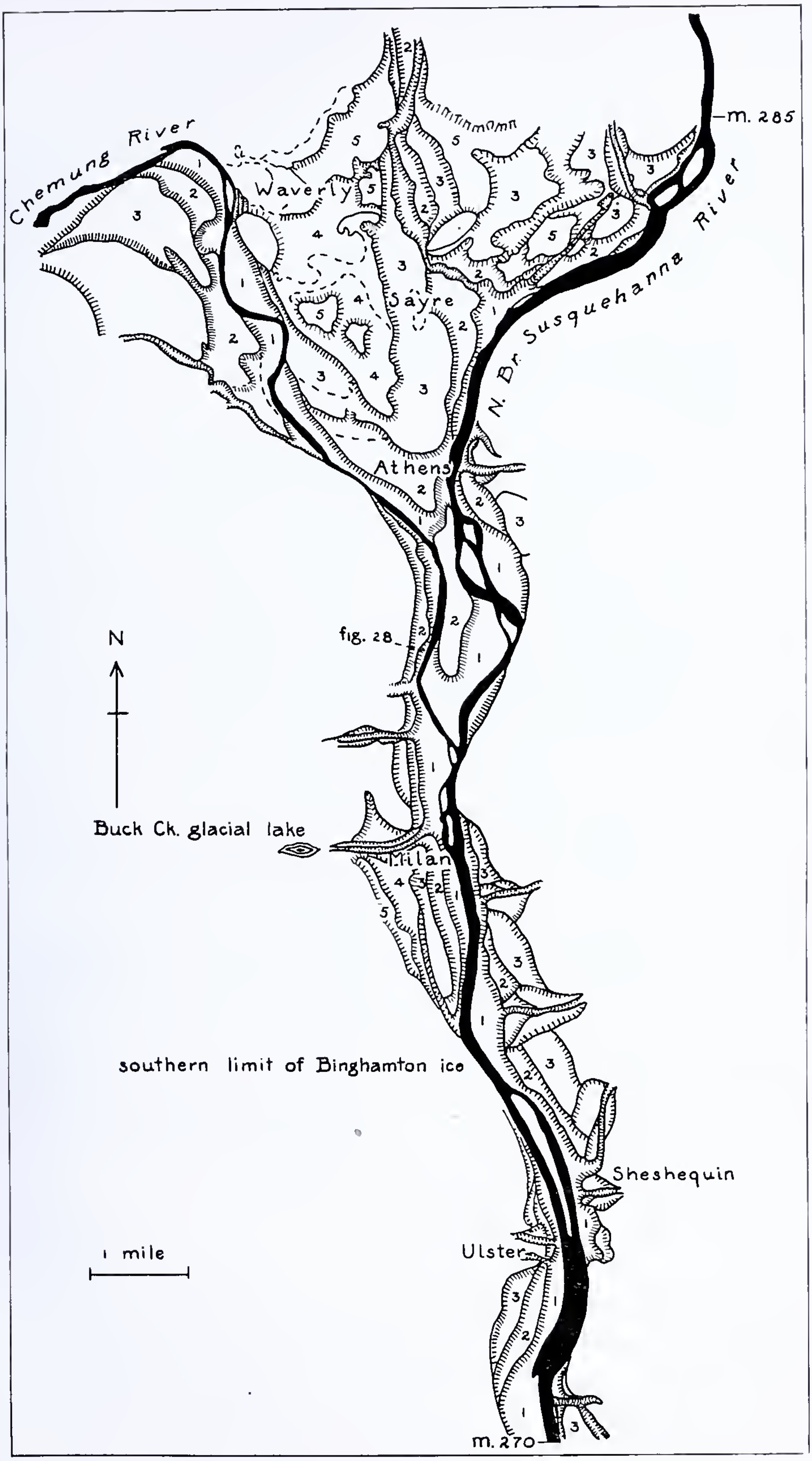

FIGURE 30. Map of Susquehanna and Chemung Rivers near their confluence at Athens showing distribution of terraces. 1. Mankato Terrace. 2. Valley Heads Terrace. 3. Binghamton Terrace including the First Binghamton Kame Terrace. 4. Second Binghamton Kame Terrace. 5. Third Binghamton Kame Terrace.

SELECTED LOCALITIES

Athens.

The terraces (fig. 30, p. 85), in the vicinity of Athens, at the junction of the Chemung River and the North Branch (m.278), illustrate the relationship between the terraces of two confluent streams. A few miles to the south the kame terraces of Binghamton age reach the limits of the Binghamton ice, and they are connected by frontal kame terraces with the Binghamton valley train terrace. The number of climatic terraces which occur on tributary creeks entering the main streams here (p. 88) corresponds with the number of valley train and periglacial terraces along the main stream. As one goes upstream along these creeks the terraces decrease in elevation and die out toward the headwaters.

As is often true of the glacial deposits in Pennsylvania, the position of maximum advance of the Binghamton ice is not marked by the presence of any strongly irregular morainal topography. Its location is recognized by the point at which the kame terraces begin their relatively abrupt descent toward the valley train terraces and by the point beyond which the till and kame deposits of the Binghamton ice cease to occur. There is a body of thick till with gently rolling topography along the right bank of the North Branch between Milan (m.276) and Greenes Landing (m.278). It covers an area of about 3 square miles. The southernmost occurrence of distinct morainal topography is at Waverly, New York, 8 or 9 miles behind the limits of maximum advance of the Binghamton ice. At Waverly the morainal topography is sharp and the moraine is made up of till, coarse kame gravel and well sorted valley train gravel. This is considered to be part of the Binghamton "terminal moraine" even though it does not coincide, in position, with the line of maximum advance of the Binghamton ice.

The tongue of ice which extended southward along the North Branch past Milan (m.276) was apparently narrow and probably did not exceed 2 miles in width. This ice tongue blocked the drainage of three small creeks which flow toward the North Branch, and formed small ice-front lakes (fig. 30, p. 85). The largest of these lakes, about ½ mile long and ⅛ mile wide, was formed on Buck Creek (fig. 32, p. 88), 1¼ miles west of Milan, about 350 feet above the river. It is now represented by a deposit of gray, calcareous, pebbly, varved clay, at least 10 feet thick.

All of the marginal kame terraces which have so far been found are younger than the ice-contact lakes. There are three distinct suites or groups of kame terraces near the glacial limit. These terraces are shown in Figure 31 (p. 87). The uppermost, or Third Binghamton kame terrace, is represented by a frontal kame terrace which lies along the right bank of the river south of Milan at a height of 120 to 140 feet. The Second Binghamton kame terrace is represented by a broad, pitted surface in the interfluve between Cayuta Creek and the Chemung River. It is about 3½ miles long and a mile wide, and is 90 to 100 feet above the river. This terrace is correlated with the kame terrace at Milan, 85 feet above the river. Beyond the limits of the Binghamton ice the profile of the Second kame terrace slopes toward the valley train on a gradient of 5.6 feet per mile. This kame terrace must have built up, at the ice edge, a large frontal kame composed of outwash. This deposit was 80 feet thick and 16 miles long. The remnants of this frontal kame, which now occur as terraces, are, therefore, called frontal kame terraces, to distinguish them from the more common type of valley train terraces, which are roughly parallel to the modern flood grade. The lower end of the frontal kame, formed at the end of the Second Binghamton kame terrace, is buried, below Wysox (m.261), by the Binghamton valley train.

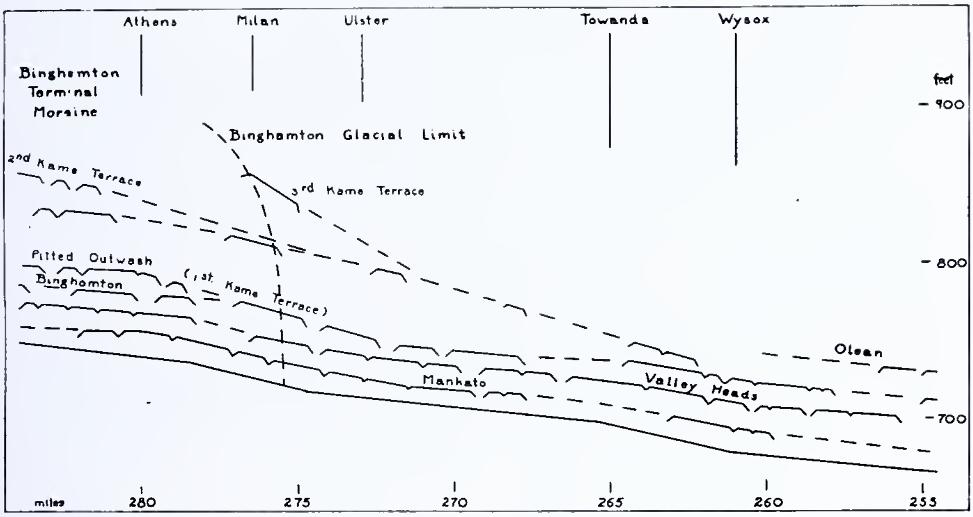

FIGURE 31. Profile of terraces and projected grade lines near Athens.

The lowest or First Binghamton kame terrace is represented by a pitted outwash plain, composed chiefly of well sorted valley train gravel, which is extensively developed in the interfluve between the North Branch and Cayuta Creek and along the right bank of the North Branch at Sayre (m.282). It is only 10 to 15 feet above the level of the Binghamton terraces with which it appears to merge laterally. The First kame terrace probably passes below the valley train terrace near Athens. The ice edge, at the time this terrace was formed, could not, therefore, have stood south of Athens (m.280). After the ice melted from this spot, a series of episodes associated with the development of younger kame terraces further north led to the building up, here, of the Binghamton valley train terrace.

The Binghamton and younger terraces in the vicinity of Athens are all broadly developed and provide the best example to be found in the Susquehanna Valley of Pennsylvania of the junction of terraces. Exposed in the center of the interfluve between the North Branch and Chemung Rivers (fig. 30, p. 85) are deposits of till and kame gravel. The area covered by such exposures is now relatively small, and they are flanked by broad valley train terraces. It is, however, likely that a much larger area was once covered by ice-contact deposits, and that large parts of the younger terraces are cut in older glacial deposits and merely covered with a veneer of younger outwash.

The valleys of both rivers are choked with gravel and the streams follow channels which contain numerous islands and bars. This condition is not the product of recent events but must have been inherited at least since Mankato time, for in the interfluve south of Athens, shown in Figure 30 (p. 85), there is a bar-shaped terrace of Valley Heads age, separated from the adjacent Valley Heads terrace at Athens by a fosse of probable Mankato age.

At the mouth of the Chemung River the Binghamton terraces appear to split as though a fan-shaped deposit of outwash from the North Branch had been built up here and was later, during the same sub-stage, cut through to form a lower terrace more closely in accord with the elevation of contemporary terraces nearby. The effects of this were, however, local and were not observed more than 3 miles above the junction of the North Branch and Chemung Rivers. No lake deposits were found in the lower part of the Chemung Valley, and this accumulation of gravel at the mouth of the river must merely have served to locally lower the gradient of the stream and lead to a building-up of the outwash plain. Similar events, described on page 105, led to the development of split terraces on the West Branch.

The terraces along the small tributary creeks entering both the Chemung River and North Branch near Tioga Point are periglacial terraces and provide an indication of the post-Binghamton climatic episodes which were effective in this region. These periglacial terraces, which are graded to the valley train terraces along the main streams,

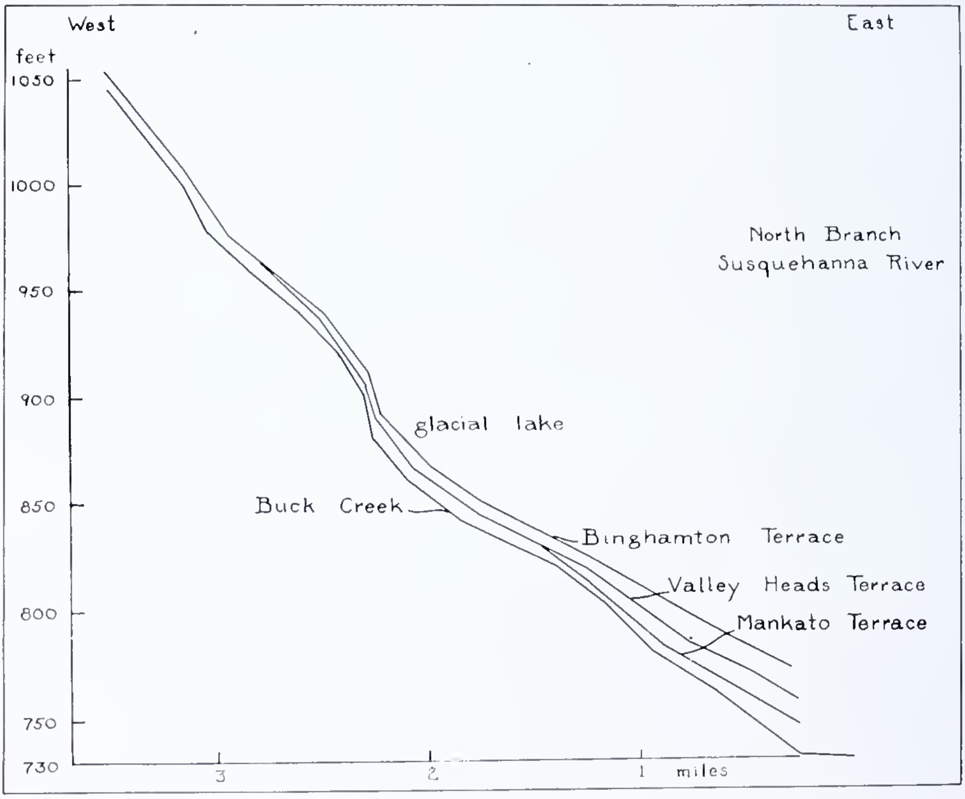

Figure 32. Profile of grade lines of terraces along Buck Creek (m.277).

decrease in height toward the headwaters of the tributary and, one after another, merge with the creek bed.

The terraces on Buck Creek, whose profiles are shown in Figure 32 (p. 88), show clearly the presence of a Binghamton terrace and two post-Binghamton terraces which are graded to the Valley Heads and Mankato terraces on the North Branch. It may be seen, in Figure 32 (p. 88), that the Mankato terrace does not extend along Buck Creek for more than a mile and a half, and that the Valley Heads terrace occurs only along the lower 2¼ miles of the creek. Each terrace appears to begin at a nickpoint in the stream grade and to owe its elevation to the headward retreat of the nickpoints. The interval of time which has elapsed since the deposition of the Mankato terrace is here represented by the headward retreat of the nickpoint on this small creek for a distance of at least a mile. The lowest or Mankato terrace must, therefore, have been deposited in the past and it cannot be considered the result of current process.

At the mouths of most of the small creeks in this area there are alluvial fans. These fans are commonly terraced, and the terraces may be correlated with the valley train terraces along the main stream and with periglacial terraces further up the creeks. It therefore appears that these fans are features of small creeks in the periglacial region and were formed during at least two distinct glacial sub-stages.

One of these two-stage alluvial fans occurs at East Athens (m.280) at the mouth of Satterlee Creek. Along Satterlee Creek there are two terraces composed of rubble brought down by the creek. The lower, which rises from the creek bed about ¾ mile above the mouth, is graded to the Mankato terrace; the other, which makes up the outer part of the fan, rises gradually above the bed of the creek and is graded to the Valley Heads terrace. It was the choking of the periglacial streams by such rubble which led, during the glacial sub-stages, to their alluviation. Erosion by the creeks during the inter-stadial times led to the dissection of these alluvial fans to leave terraces.

Quicks Bend.

Along the North Branch of the Susquehanna River between Wyalusing (m.245) and Mehoopany (m.225) the river flows in incised meanders across a zone of morainal topography and one may observe, here, both the manner in which the valley train terraces occur relative to the river bends and the way in which the terraces are related to a recessional halt of the glacial ice.

A zone of morainal topography, 7 to 10 miles wide, which represents one or more halts in the recession of the Olean ice front, crosses the river in a northnortheast-southsouthwest direction. Along the North Branch it is represented by deposits of thick till and coarse gravel, with slightly irregular topography, which occur in rock-defended positions on the downstream side of Quicks Bend (m.240) and at Scottsville (m.231). In the valley of Wyalusing Creek, 1 to 3 miles above its mouth, and at Wilmot, 5 miles southsouthwest of Wyalusing, there are bodies of gravel which have a distinct morainal topography. On the upland surface, 3 miles north of Quicks Bend, 500 to 800 feet above the river, the topography of the moraine is subdued and it appears to be little more than a zone of thick till with gently undulating topography. This moraine appears to resemble that at Milan (m.276) and Waverly (m.285), in that the zone of morainal deposits of coarse gravel lies behind the limits of the ice as may be indicated by the deposits of till. This moraine, however, is a recessional moraine, for there is no difference in the amount of weathering on either side of it and a separate valley train terrace, whose presence would have indicated a lapse of time between this and the other glacial sub-stages, was not formed.

The presence of a frontal kame indicates that the ice edge stood here for a time sufficiently long to build an alluvial fan at its front. Evidence, which would indicate whether a re-advance of the same ice or merely a still-stand of the ice edge occurred here, has not been found. At Quicks Bend this frontal kame appears to slope toward the Olean valley train terrace and pass beneath it within 5 miles. However, in this part of the river, the Lower Olean kame terrace of the ice edge at Berwick is less than 20 feet above the Olean valley train terrace, and the frontal kame may have joined this kame terrace instead of passing below the level of the valley train.

The valley train terraces at Quicks Bend parallel the river along the inside and downstream side of the bend, so that they have an S-shaped pattern. In this part of the river the Olean terraces may be broad, but the younger terraces are generally narrow and rarely exceed 300 feet in width. These terraces, where distinctly developed, have an average gradient toward the river of slightly more than a degree. A few terraces slope toward the river at an angle of less than 15 minutes. It is, therefore, apparent that there has been an insignificant tendency toward the development of a slip-off slope on the inside of these meanders, of which Quicks Bend is an example, during the time when the valley train terraces were formed. This is taken as evidence that the river was not significantly lowering its bed at the time when the terrace surfaces were being formed. The erosion of the river bed or valley fill and the deposition of the terrace gravels occurred during separate and distinct times in the history of the valley.

The valley train terraces along the north side of Quicks Bend are narrow and have slopes of 5 or 6 degrees. They are recognized by breaks in the slope at their lower edges which may be traced downstream to points where the terraces are more distinct. This relatively high gradient of the terrace surfaces is thought not to represent the initial slope of the terraces as formed by the deposition of gravel, but rather to represent the effects of slopewash and slumping from the adjacent slope. Many remnants have probably been obscured and have passed unobserved as the result of these processes.

The rock spurs which project from the valley walls along the upstream side of the bends are both narrower and shorter than the bends of the river. They indicate that the river once followed a much different course in the past. Since that time the meander at Quicks Bend has increased its amplitude by 20 per cent and has moved downstream by one-half its length. The change in the shape and position of the valley train terraces has been insignificant. The lateral development of the meanders must, therefore, have occurred at some pre-Wisconsin time. It is likely that the introduction of large quantities of sand and gravel into the North Branch during earlier glacial stages led to a decrease in the erosion of the bed of the river and increased development of the meanders.

Berwick.

At Berwick (m.159), where the North Branch crosses the boundary of the Olean glacial deposits, there are several well developed kame terraces and the terrace remnants of the frontal kames which were formed at the end of the marginal kames. These remnants are shown in Figure 33 (p. 91). The remnants of the four lowest marginal kames are genetically related to frontal kames and may be traced for several miles behind the terminal ice position. At Berwick they may be identified as :(1) First Olean kame terrace at 566 feet above sea level, or 86 feet above the river[1]; (2) Second Olean kame terrace at 578 feet above sea level, or 98 feet above the river; (3) Third Olean kame terrace at 590 feet above sea level, or 110 feet above the river; and (4) Fourth Olean kame terrace at 638 feet above sea level, or 158 feet above the river.

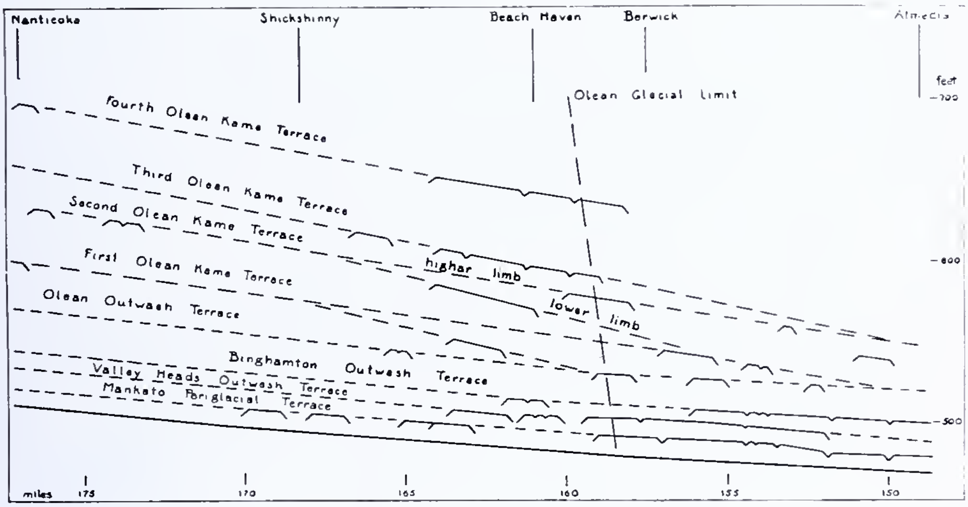

FIGURE 33. Profile of terraces and projected grade lines near Berwick.

At the downstream end of each marginal kame, at the edge of the ice, a frontal kame was formed. The waters which had followed the ice margin flowed across this steeply sloping kame and thus downstream into the unglaciated valley below. During the earliest stages this frontal kame was relatively steep and the deposit of gravel in the valley below relatively thin. During later stages, as the valley fill became built up, the frontal kames attained a lower gradient, extended further downstream and merged with the main valley train. As a result, the frontal kame of each successive marginal kame terrace was incised in the previously formed frontal kame and extended beyond it. Each new frontal kame buried the lower parts of the older frontal kame and helped to build up the valley train along the valley below.

---

[1] These measurements were made to the break in slope at the outer edge of the terrace, because this is a recoverable point. This elevation may, however, be below the level of the original alluvial surface.

Some of the frontal kames appear to have been terraced while they were still growing and still carrying the waters of the marginal kame terraces from which they were derived at the beginning of their formation. This result is apparently due to partial retreat of the ice front without complete abandonment of the marginal kame channels. The retreat of the ice caused a retreat of the head of the frontal kame and the terraces cut into these frontal kames usually have steeper grades than the main frontal kame, as though the retreat of the ice front had been associated with an increased flow of waters, a dissection of the frontal kame at its head, and continued deposition at its lower extremity.

The Fourth kame terrace is a broad terrace which extends along the right bank for 6 miles above Berwick. Throughout this distance it maintains a gradient of 3 feet per mile. No remnants of a frontal kame related to this terrace were found below Berwick. If such a frontal kame existed its gradient was presumably much steeper than that of the marginal kame terrace or of any of the younger frontal kames, and consequently it was largely buried by the deposits which extended downstream from the end of the younger marginal kames. The marginal kame terrace of this "stage" was traced upstream to Plymouth (m.180) where it has an elevation of 750 feet and thus appears to correlate with the 745-foot terrace in the Lackawanna Valley, described by Itter (1938).

TABLE 36. *Geologic Section in Road Cut on west side of U. S. Highway 11, 2 miles north of Hicks Ferry, Shickshinny, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loess, *Olean,* buff, loose, oxidized, non-calcareous	0	9
2.	Sand, *Olean,* buff, loose, coarse-grained, silty, non-calcareous	0	5
3.	Sand, *Olean,* buff, compact, coarse-grained, silty, non-calcareous	2	7
4.	Gravel, *Olean,* buff, medium- to course-grained, in medium sand matrix, non-calcareous	15	0
5.	Sand, *Olean,* buff, coarse-grained, cross-bedded, contains coal-rich bands, sand grades into silt toward base, non-calcareous	75	0
6.	Sand and silt, *Olean,* buff, composed of alternating layers, 6 to 12 inches thick, of fine-grained sand and coarse silt. Horizontally bedded, non-calcareous	12	0
7.	Silt and clay, *Olean,* red, varved, contains limonite concretions, non-calcareous	5	0
8.	Sand, *Olean,* buff, fine-grained, non-calcareous. To base	7	0
	Total	117	9

Non-calcareous
Depth of oxidation: at least 117 feet

The deposits of the Fourth kame terrace are exposed in a cut on the north side of U. S. Highway 11, 2 miles north of Hicks Ferry (m.163). A diagram of this exposure is shown in Figure 34 (p. 93) and a section is given in Table 36 (p. 92). This deposit is composed largely of cross-bedded, coarse-grained sand, overlain by a horizontally bedded deposit of medium- to coarse-grained gravel, which in turn is overlain by a thin deposit of coarse-grained sand. The sand grades upward into a surface deposit of buff-colored silt or loess. The cross-bedded

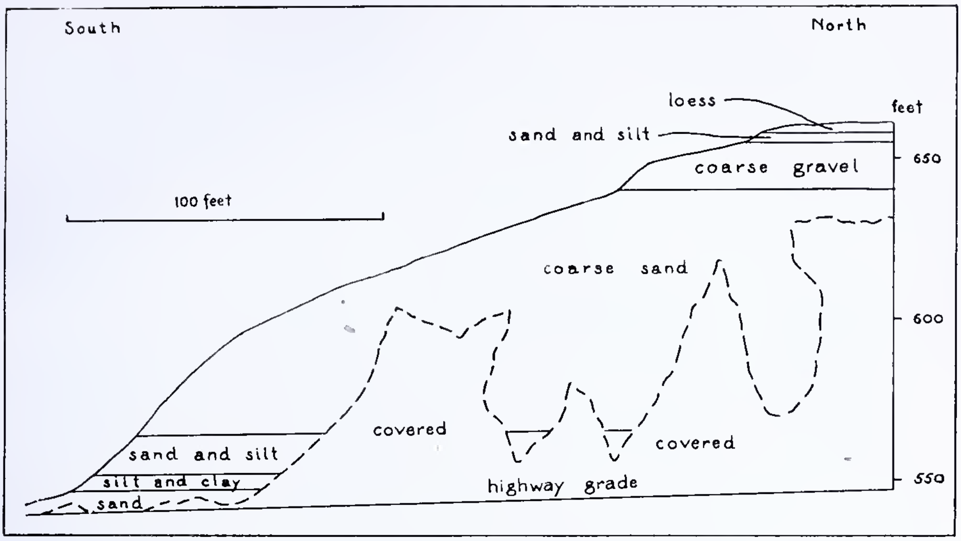

Figure 34. Geologic section of road cut along U. S. Highway 11 near Hicks Ferry (m.163).

sand grades downward into sand and silt. The sand and silt layer is made up of alternating horizontal bands, 6 inches to a foot in thickness, of fine-grained sand and coarse-grained silt. At a similar exposure, 200 feet to the south, one of the sand layers, here 10 feet below the surface, contains numerous limonite concretions in the form of: (1) poorly consolidated, sandy, black masses; (2) flat, platy bodies of black limonite, about ¼ inch thick, which have weathered on the surface to brown limonite; and (3) columnar masses, some of which contain roots or a core of gray, clayey silt. At the bottom of both exposures there is a thin bed of red clay and silt in which ½-inch-thick layers of clay alternate with 2-inch bands of fine-grained sand or silt. These clay and silt layers indicate that a small ice-front lake existed here during the first part of the glacial recession and before the great body of gravel was deposited. Below the lake sediments there is another deposit of fine sand or alternating silt and fine sand.

The Third kame terrace extends from Hicks Ferry (m.163) to Berwick. Here it has a slope of 4 feet per mile. No remnants were found in the narrows between Hicks Ferry and Nanticoke (m.177). It may, however, be correlated with the 720-foot terrace in the Lackawanna Valley, described by Itter (1938).

The Second kame terrace or system of kame terraces contains the most prominent kame terraces along the North Branch for 40 miles above Berwick. Terrace remnants of this recessional stage were found along the river as far as McKune (m.206) and it is likely that this point was the northern limit of the zone of stagnant ice during this stage. However, the upstream limit of this as well as all other marginal kame terraces has no distinctive feature which indicates termination. There are no kame hills or change in gradient. The upstream limit is inferred by the lack of more terraces at suitable elevation.

Generally the terraces of this recessional stage are composed of fine-grained gravel and sand, overlain by about 10 feet of coarse gravel and capped by a loess deposit of irregular thickness. A typical section (Table 37, p. 94), is exposed in the pit of the Hunlock Creek Sand and Gravel Company, 3 miles southwest of Hunlock Creek (m.174). The lower 60 feet of the exposure consists of slightly cross-bedded, medium- to fine-grained gravel, in which there are occasional layers of coarse gravel. The beds dip fairly consistently toward the river at an angle of about 20 degrees. This is overlain by a deposit, about 10 feet thick, of poorly sorted, coarse-grained gravel and scattered lenses of medium-grained sand. The surface is covered with a deposit of loess 1 to 5 feet thick.

TABLE 37. *Geologic Section in the Pit of the Hunlock Creek Sand and Gravel Co., 3 miles southwest of Hunlock Creek, Shickshinny, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loess, *Olean*, buff	1 to 5	0
2.	Gravel, *Olean*, buff, coarse, poorly sorted, with scattered lenses of medium sand, non-calcareous	10	0
3.	Gravel, *Olean*, buff, medium-grained with layers of coarse gravel, gently cross-bedded, non-calcareous	60	0
	Total	71 to 75	0

Non-calcareous
Depth of oxidation: at least 75 feet

The river valley here, at the elevation of this terrace (634 feet above sea level, or 124 feet above the river), is only about 1500 feet wide and, if one is to assume that a body of ice, large enough to last for a long period of time, stood in the valley, the marginal outwash channel in which this gravel was deposited must have been very narrow. Each flood which passed along it must have completely covered it. It is, therefore, unlikely that the deposit of coarse gravel overlying finer-grained gravel is the result of a migration of the stream channel over its previously deposited floodplain, and one must assume that the change in the size-grade of the deposits is the result of a change in the regime of the meltwater streams at the close of a minor halt of the ice.

Similar deposits of the same ice halt are exposed in a pit 2 miles south of Shickshinny (m.168). A section of this exposure is given in Table 38 (p. 94). At the surface is a 5-foot layer of buff-colored, coarse-grained gravel. It is underlain by a 40-foot layer of horizontally bedded, fine sand and silty, fine sand. At the base is a 3-foot layer

TABLE 38. *Geologic Section in Sand Pit on west side of U. S. Highway 11, 2 miles south of Shickshinny, Shickshinny, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Gravel, *Olean*, buff, coarse-grained	5	0
2.	Sand, *Olean*, buff, fine-grained, contains silty layers, horizontally bedded, non-calcareous	40	0
3.	Silt, *Olean*, red, clayey, contains horizontal beds of fine sand	3	0
4.	Sand, *Olean*, buff, medium-grained, coal-rich, gently cross-bedded, non-calcareous	10	0
5.	Sand, *Olean*, buff, medium- to coarse-grained, cross-bedded in places, non-calcareous	15	0
6.	Gravel, *Olean*, brown, fine-grained, rusty, non-calcareous. To base	4	0
	Total	77	0

Non-calcareous
Depth of oxidation: at least 77 feet

of red, clayey silt with interbedded fine sand. Below the clay is a deposit of sand 25 feet thick. At its base 1 to 2 feet of fine-grained, rusty gravel is exposed.

The deposit of red clay appears to correlate with the lake deposit described on page 93 as occurring beneath the Fourth kame terrace. In that place, as here, the clay is both underlain and overlain by sand. It therefore appears that only the upper part or veneer of coarse gravel belongs to the Second kame terrace sequence. The bulk of the deposit belongs to the Fourth kame terrace.

This hypothesis is supported by the occurrence of a similar deposit exposed in a gravel pit 1 mile northwest of the Susquehanna River at Berwick (m.159). This deposit (Table 39, p. 95) consists of a layer of buff-colored silt or loess 3 to 5 feet thick, at the surface, underlain by 10 to 15 feet of coarse-grained gravel. Below this is exposed 35 feet of a deposit of medium- to fine-grained gravel. This pit lies at or beyond the maximum position of the Olean ice. However, the deposits of the Fourth kame terrace and the Third kame terrace filled the valley to levels 10 and 55 feet above the present terrace. The present terrace was cut into the deposits of pre-existing kame terraces and only the upper 10 to 15 feet is the result of alluviation at the time of the Second kame terrace.

TABLE 39. *Geologic Section in Gravel Pit 1 mile northwest of Susquehanna River bridge at Berwick, Shickshinny, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS	
		feet	inches
1.	Loess, *Olean,* buff	3 to 5	0
2.	Gravel, *Olean,* coarse, oxidized, non-calcareous	10	0
3.	Gravel, *Olean,* medium-grained, well sorted, non-calcareous	35	0
	Total	48 to 50	0

Non-calcareous

According to Itter (1938), remnants of the Second kame terrace stage, which he called the "685-675-foot terrace," at Parsons (m.186) and Miners Mills (m.186) are composed of a lower horizon of intricately cross-bedded sands and gravels, overlain by an upper zone of horizontally bedded, coarse gravel. He also described a terrace, probably equivalent to the Second kame terrace, at an elevation of 720 feet above sea level at Old Forge and Moosic in the Lackawanna Valley, as composed of a series of sand and gravel beds in which sand predominates, overlain by 3 to 5 feet or more of coarse, horizontally bedded gravel.

A terrace on Mill Creek (m.186), composed of deposits of similar characteristics, was described by Darton (1914) as made up largely of sand in inclined beds, capped by a thin layer of gravel and sand. The sand was described as an alluvial deposit of interbedded fine, coarse, and gravelly sand; and the gravel cap was described as a distinctly separate, 2- to 5-foot bed of a till-like, heterogeneous mixture of boulders, gravel, sand and clay.

The common occurrence, over a distance of 35 miles, of a bed of coarse gravel at the surface of the Second kame terrace, underlain by distinctly finer-grained sediments, indicates that this feature is not local. The interpretations previously given to separate exposures in this terrace may, therefore, be applied to the larger area. It then becomes apparent that many of the terraces of the Second kame terrace stage were formed by the erosion of previously deposited sediments of older kame terraces. This change from sedimentation to erosion does not appear to have been the result of an increase in stream velocity attendant upon a steepening of the gradient, for the gradient of the Second kame terrace profile along this part of the river is 3 feet per mile, as compared with 3.6 feet per mile for the Third kame terrace, 3 feet per mile for the Fourth kame terrace, 3.2 feet per mile for the Lower kame terrace, and 1.7 feet per mile for the Olean valley train terrace. One must, therefore, suppose that this erosion was the result of a change in the regime of the marginal streams, which probably involved an increase in the size of the floods.

The deposition of the "gravel cap" or layer of coarse gravel at the top of the Second kame terrace was apparently another result of the change in the regime of the streams, explained on page 94. In many instances the deposits which lie beneath the gravel, and which are supposed to be similar to those which were eroded, do not appear to contain a sufficient quantity of large pebbles and cobbles to permit an explanation of the "gravel cap" by the selective erosion of fine sediments. It therefore is likely that a large part of the coarse surface material was derived from the barren valley walls, where bodies of thawed and saturated till and gravel slid down the slopes and into the channel. On smaller streams, as in the locality on Mill Creek which Darton described, the floods were probably weak, the amount of sorting and reworking of the rubble is slight, and one might expect the rubble to more closely resemble the till from which it was derived.

Near the glacial boundary the profile of the Second kame terrace splits into three limbs. The higher limb continues downstream at the same gradient as upstream and apparently passes beneath the level of the Olean valley train terrace 17 miles downstream. The intermediate limb increases its gradient to 3.7 feet per mile at a point about 7 miles behind the glacial boundary. The lower limb increases its gradient to 6 feet per mile, about 7 miles behind the glacial boundary, and passes beneath the frontal kame of the First kame terrace about 2 miles below the glacial boundary.

Terraces of the First kame terrace stage were found scattered along the valley of the North Branch above Berwick (m.159) for 72 miles. Near Osterhout (m.210) a terrace of this stage occurs at 670 feet above sea level, or 88 feet above the river. Here it has a gradient of 1.3 feet per mile. The terrace is composed of medium- to coarse-grained gravel, overlain by about a foot of buff-colored, pebbly loess.

About 9 miles behind the glacial boundary at Berwick, the First kame terrace profile splits into two limbs. The upper limb continues downstream at a gradient of 2.8 feet per mile, passes over the lower limb of the Second kame terrace, and either merges with the Olean valley train terrace or extends beneath it, 9 miles beyond the glacial boundary. The lower limb increases its gradient to 6.3 feet per mile and passes beneath the Olean valley train terrace level one mile behind the glacial boundary.

The various kame terraces near Berwick indicate by their morphology and stratigraphy that the disappearance of ice from this part of the river was interrupted from time to time by changes in the rate of melting and the rate of flow along the channels at the edge of a stagnant tongue of ice. The early stages of the recession were presumably slow, for the sediments are fine-grained and a small lake formed in what was later to become the path of a major outwash channel. Gradually these fine-grained deposits filled the void between the ice mass and the valley walls to a depth of at least 120 feet. As they did so they extended beyond the front of the ice mass as a large frontal kame. At this time active ice may have stood in the Wyoming Valley. This stage was interrupted by increased erosion, presumably the result of an increased rate of flow in the marginal channels. This brought about the erosion of the previously deposited sediments and the development of the Third kame terraces. This terrace level probably represents a temporary stabilization of stream flow. A second stage of accelerated erosion led to the development of the Second kame terraces and to the deposition of frontal kame deposits downstream beyond the edge of the ice. The streams which deposited this frontal kame emerged from the corresponding ice tongue at a lower elevation and, therefore, had a slightly lower gradient. The frontal kames of the earlier stages were dissected and their deposits either buried or swept away. During this stage, rubble moved down the mountain slopes and choked the flow in the streams along the ice margin, thereby providing a source of coarser alluvium which remained on the terrace as a "gravel cap." Late in the Second kame terrace stage, accelerated erosion began again. This presumably started with the dissection of the frontal kame. The First kame terraces were graded to the new level which resulted. At this time the glacial boundary had retreated about 10 miles upstream from its maximum position and an ice tongue about 60 miles long lay in the valley of the North Branch between the ice edge and Meshoppen (m.228), about 38 miles to the north. This represents a zone of stagnation 30 miles wide. Still another episode of erosion followed the development of the First kame terrace. Probably the remaining ice, which by now must have been very thin, melted rapidly. Any later episodes in its history have been buried by the Olean valley train deposits derived from ice which stood north of Wysox (m.261) and whose frontal kame deposits were obscured by the advance of the Binghamton ice.

TERRACES OF THE WEST BRANCH, SUSQUEHANNA RIVER

DESCRIPTION OF VALLEY

The terraces of the West Branch, Susquehanna River, (fig. 35, p. 98 and Table 41, p. 104) were traced from Lock Haven (m. 190) to its junction with the North Branch at Northumberland (m.123). This part of the valley is readily divisible into an upper and a lower section because of differences in the structural and topographic features of the countryside and in the character of the river grade line.

In the upper section, the river flows eastward for 37 miles along the north flank of Bald Eagle Mountain. The valley is 1 to 2 miles wide and a terrace of Binghamton age, about 21 feet above the river, predominates throughout. All of the other stages or sub-stages are represented only by inconspicuous terraces which cling to valley walls that rise directly from the river or from the 21-foot terrace, for 400 or 500 feet on the north bank, and 1000 feet on the south bank.

The stream gradient in this section is gentle and unbroken. However, 5 miles above its lower end, at an elevation of 490 feet above sea level, where the river approaches the bend around the end of Bald Eagle Mountain (m.156), there is the first of a series of sharp drops by which the river falls 60 feet in 24 miles. A second nickpoint, at 475 feet above sea level, occurs at the beginning of the bend at Bald Eagle Mountain (m.153), and a third, at 455 feet above sea level, at the upstream end of the watergap through the western end of the Muncy Hills (m.146).

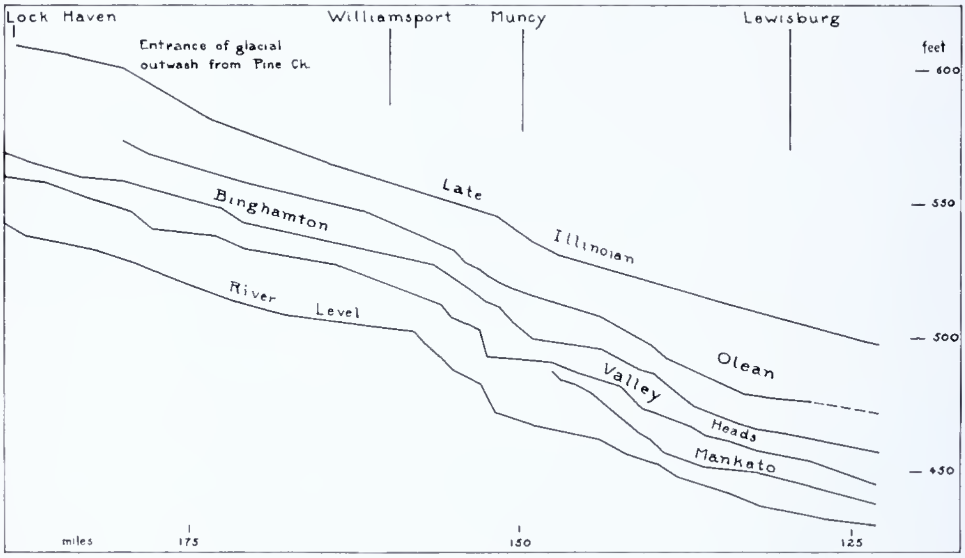

FIGURE 35. Profile of grades of the several terrace systems on the West Branch, Susquehanna River.

South of the end of Bald Eagle Mountain the lower section of the West Branch flows in a valley which is generally narrower than that immediately upstream. However, flights of terraces are common. After the river rounds Bald Eagle Mountain (m.150), it flows southwestward to a watergap in the western end of the Muncy Hills at Montgomery (m.145), and thence southward across White Deer Valley to a lesser watergap in the eastern end of South White Deer Ridge at Watsontown (m.139). Between Watsontown and the watergap at Montour Mountain (m.128), the river flows through a region of shale and limestone hills which rise steeply about 100 and 250 feet above the river. For the remaining 4 miles of its course below Montour Mountain, the West Branch is flanked by a 20-foot terrace, above which the walls rise steeply to a rolling surface about 400 feet above the river.

TERRACES

General Statement.

Terraces which are the remnants of six different stages of alluviation occur along the West Branch (fig. 35, p. 98). Of these the lower three are climatic terraces of periglacial origin, and the others are valley train terraces. Along the upper section of the river the height of the different terraces is lower than for the corresponding terraces along the lower section. The names and average heights of the terraces in the lower section of the river are: Mankato terraces, 10 feet; Valley Heads terraces, 18 feet; Binghamton terraces, 28 feet; Olean terraces, 45 feet; and Illinoian terraces, 66 feet. Along the upper section the average heights of the terraces are: Valley Heads, 13 feet; Binghamton, 22 feet; Olean, 37 feet; and Illinoian 63 feet.

In general, all of the terraces are covered with a surface veneer of buff- to tan-colored, fine-grained sand or silt. In many instances this surface deposit appears to have been laid down by the wind. However, the sand and silt on the post-Binghamton terraces appear to have been deposited by floods of the West Branch. The Mankato terraces, which are normally covered by major floods, have a mantle of tan-colored, clayey silt, silt or fine sand. The Valley Heads terraces have a mantle of light-tan to buff-colored sand or silt and, where the terraces are not covered by modern floods, the silt appears to be less clayey in texture than that in the Mankato terrace. The cover of the Binghamton terraces is a light-tan to buff-colored silt. That of the Olean terraces is similar, but always buff-colored. The Illinoian terraces are characterized by the red to reddish-brown color of their gravel, but in some instances the gravel is overlain by buff-colored sand or silt, presumably of later age. In other instances the gravel is overlain by slopewash or rubble derived from the adjacent slope.

The soils on these terraces in Lycoming County were mapped by Stevens and others (1928). In general, the soils of the Mankato and Valley Heads terraces were identified with the Moshannon series, and those of the higher terraces with the Wheeling series. The fact that the Soil Survey makes no distinction between the surface soils of the Binghamton, Olean and Illinoian terraces implies that they are all of one age. They can be attributed to wind deposition in Binghamton time.

The lithology of the pebbles of the valley train gravel and the glacial deposits along the West Branch is quite different from that which prevails along most of the North Branch. This is shown in Table 3 (p. 18). The gravel and till deposits of the Olean sub-stage contain no limestone, granite or gneiss pebbles. These deposits are made up entirely of pebbles from rocks which occur in Pennsylvania. The proportion of pebbles, in the Olean valley train deposits along the lower section of the West Branch, which were never transported by glacial ice, appears to be relatively high, and to indicate that the outwash which the West Branch contributed to the main stream was thoroughly contaminated by rock fragments derived from the valley walls by frost action (p. 104).

The age of these terraces was determined by tracing them upstream from the junction with the North Branch at Northumberland (m.123) and downstream from the Olean glacial boundary on Muncy Creek (m.158), Little Muncy Creek (m.165) and Loyalsock Creek (m.163). The Illinoian gravels were identified by the similarity in weathering with the Illinoian "moraine" at Selinsgrove (m.116), described on page 44.

The profiles of the terraces (fig. 35, p. 98) conform, in a general sense, to the surface of the mean low-water, or essentially to the bed-rock floor, of the river. However, at nickpoints where the grade becomes steeper downstream, the stream velocity is higher. Presumably this relationship was also true in the past. At these places, as near Muncy (see also p. 103), the terraces stand closer to bed-rock or, in other words, decrease in height above the river. As the terrace profiles converge, the terraces are distinguished with greater difficulty. Downstream from the nickpoints, the stream velocity again decreases and presumably did in the past. The terraces again are found at the heights above the river at which they occur upstream.

Mankato Terraces.

The Mankato terrace profile is incomplete, in the sense that Mankato terraces cannot be distinguished upstream from Montgomery (m.145). The Mankato terraces approach the Valley Heads grade upstream. Presumably, above Montgomery, the floods of the Mankato sub-stage flowed at levels high enough to top the Valley Heads terraces, which therefore are the composite product of both sub-stages. This relationship indicates that erosion of the channel of the West Branch, during the Mankato-Valley Heads interstadial episode, did not extend above Montgomery.

The Mankato terraces extend along the West Branch for 22 miles above its mouth. They are in all instances narrow and usually occur at the mouth of a tributary creek. The flood of March 1936 covered the outer edge of the Mankato terraces. In most places the edge was flooded to a depth of 8 or 10 feet. Since the Mankato terraces are commonly covered by floodwaters, they are mantled by modern alluvium. Their attribution to Mankato time is based on the same correlation as that used on similar terraces of the North Branch (p. 79).

Valley Heads Terraces.

Along the lower 20 miles of the West Branch there is a nearly continuous terrace of Valley Heads age on both sides of the river. It is broadly developed and easily traced to the Valley Heads terrace on the North Branch at Northumberland (m.123). Except below Lewisburg (m.130), these terraces were not covered by the flood of March 1936.

Above Fairfield (m.155) its occurrence is similar to that of the Mankato terraces further downstream, for here the Valley Heads is represented by narrow terraces, usually 8 to 10 feet below those of Binghamton age. These terraces, which may lie within 4 feet of the Binghamton terrace level, are best developed near the mouths of small tributary creeks. Unlike the Valley Heads terraces further downstream, these terraces were covered by the 1936 flood to depths of 15 feet.

Binghamton Terraces.

With the exception of a break of about 6 miles at Montour Mountain (m.128), the valley fill of the Binghamton sub-stage forms an almost continuous line of terraces from Northumberland (m.123) to Lock Haven. Along the lower section of the West Branch these terraces are about 28 feet above the river. They gradually decrease in height upstream, to about 20 feet at the river bend at Bald Eagle Mountain.

Along the upper section of the West Branch, between Montoursville (m.157) and Lock Haven (m.190), the valley is occupied, for the most part, by a single, broad, unbroken terrace composed chiefly of sand with some gravel and overlain by a deposit of tan- to buff-colored silt. This terrace is identified with the Binghamton sub-stage because it lies 15 feet below the Olean valley train gravels deposited near the mouth of Pine Creek (m.179), with no terrace intervening, and because it may be traced across the nickpoints near Muncy (m.150) to the Binghamton terraces near the mouth of the West Branch.

The Binghamton terrace along the upper section was submerged during the flood of March 1936 to depths of at least 5 feet. Presumably similar flooding occurred during the past, and deposits, whose age ranges from Binghamton to the present, overlie the Binghamton gravels in this terrace.

Olean Terraces.

The Olean terraces are the lowest glacial outwash terraces along the West Branch; all lower terraces are periglacial terraces. No remnants of Olean valley fill were found south of the watergap at Montour Mountain (m.128). They were, however, traced downstream from the Olean glacial boundary on Muncy Creek at Picture Rocks (m.158) to the junction of this creek and the West Branch and thence to Montour Mountain. This was supported by similar correlations made along two parallel creeks referred to on page 100. Along the lower section of the West Branch the Olean terraces lie about 17 feet above the Binghamton terraces and 21 feet below the Illinoian terraces. No terraces lie between the tan-colored Olean valley train gravel terraces and the red gravel terraces of the Illinoian glacial stage.

Olean terraces were found in protected places along the river as far as Pine Creek (m.180), where the outwash from the Olean glacial boundary at Lloyd enters the West Branch.

Illinoian Terraces.

The Illinoian valley train terraces occur in scattered localities as thin deposits 55 to 70 feet above the river. The Illinoian outwash terrace profile is paralleled, throughout the course of the West Branch below Lock Haven, by that of higher terraces, about 82 feet above the river and between 120 and 160 feet above the river, which are also presumed to be Illinoian. These terraces contain gravel which, in degree of weathering, resembles that of the Illinoian valley train terraces. Probably they are Illinoian kame terrace remnants. However, this interpretation requires an extension of the Illinoian glacial boundary westward from the position given by Leverett (1934), near the mouth

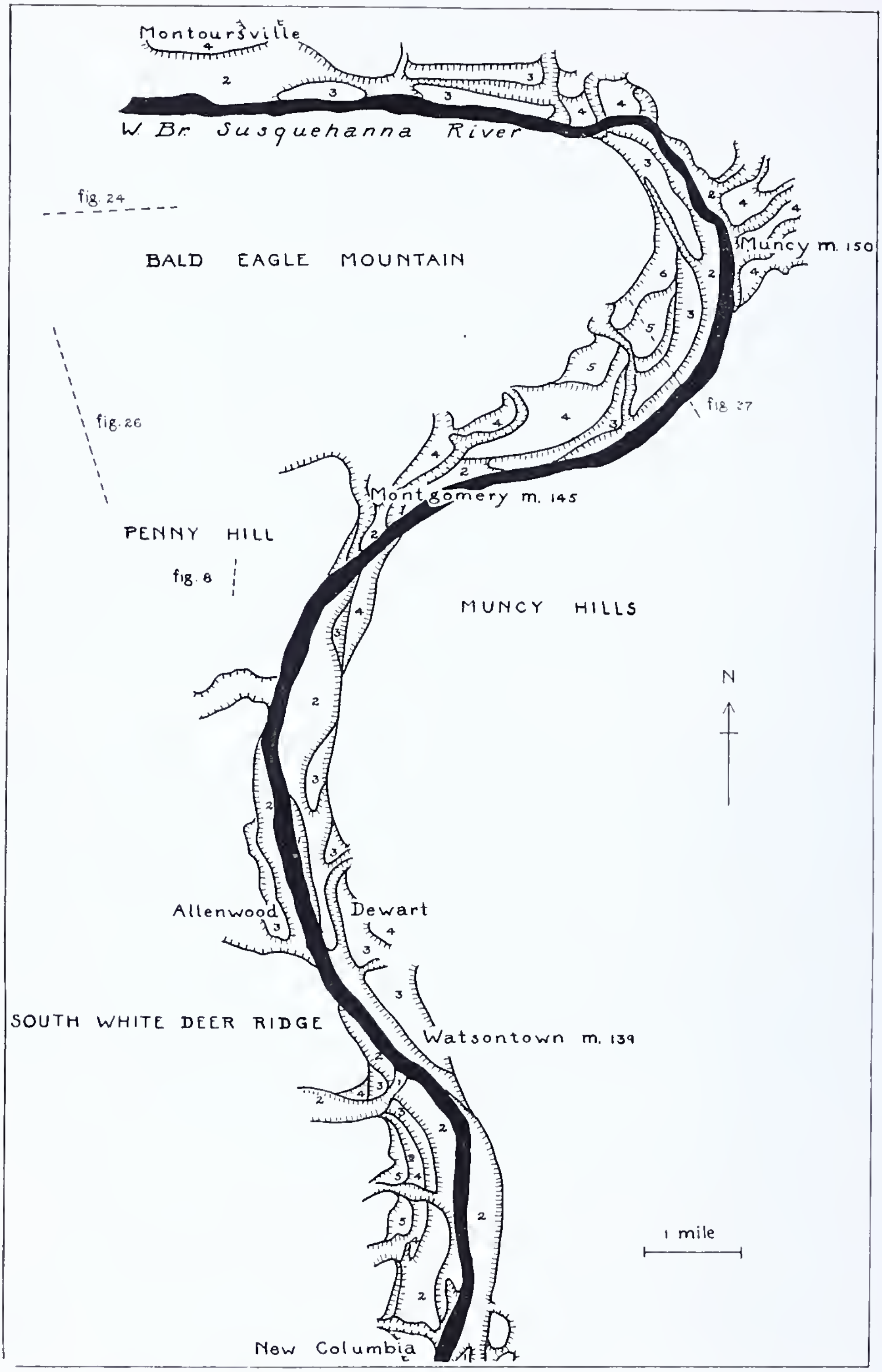

FIGURE 36. Map of West Branch of Susquehanna River near Muncy showing location of Figures 8, 24, 26, and 37 and distribution of terraces.

LEGEND

Terrace Number	*Terrace*	*Terrace Number*	*Terrace*
1.	Mankato Terrace	4.	Olean Terrace
2.	Valley Heads Terrace	5.	Late Illinoian Terrace
3.	Binghamton Terrace	6.	Illinoian (?) Terrace

of Lycoming Creek (m.163), to some point beyond Lock Haven (m.190). These terraces might also be interpreted as the deposits of an earlier sub-stage. However, these terraces correlate with the Illinoian morainal deposit at Selinsgrove (m.116) and cannot be older than that deposit.

SELECTED LOCALITIES

Muncy.

At Muncy (m.150) (fig. 36, p. 102) the West Branch follows a course which bends around the eastern end of Bald Eagle Mountain and then passes through a watergap in the western end of the Muncy Hills (m.145). A major nickpoint, at which the river falls 10 feet in a mile, occurs about 3 miles west of Muncy. The terraces at this locality (fig. 37, p. 106) are fairly well preserved and provide the best available illustration of the passage of alluvial terraces across a nickpoint.

Periglacial climatic terraces of the Mankato, Valley Heads and Binghamton sub-stages, valley train terraces of the Olean sub-stage and Illinoian stage, and a pre-Illinoian rock bench, which was presumably cut during Somerville time, are present here. The Mankato terrace does not exist as a separate terrace above Montgomery (m.145).

The Mankato terraces, where found, consist of narrow bodies of tan-colored, fine-grained sand or silt about 15 feet above the river. Their soil was generally mapped by Stevens and others (1928) as the Moshannon fine sandy loam. The Valley Heads terraces are covered by tan- to buff-colored, fine-grained sand or silt. No gravel was found here, but there are, in these terraces, scattered boulders which may be relics of the deposits of an earlier sub-stage. The Binghamton terraces are the broadest terraces along this part of the river. They are composed of tan- to buff-colored, medium- to fine-grained silt or fine-grained sand. Along the right bank between Muncy and Montgomery the terrace consists of 2 to 3 feet of buff-colored, fine-grained sand or silt, underlain by several feet of weathered valley train gravel. This terrace appears to have been cut on an earlier deposit of Illinoian gravel and covered with a veneer of Binghamton sand.

The Olean terraces contain a greater variety of sediments. They consist of coarse- to fine-grained sand, medium- to fine-grained valley train gravel, and scattered cobbles and small boulders. The Olean gravel which lies in a gravel pit one mile south of Montgomery (m.145) consists of a 5-foot layer of horizontally stratified, coarse-grained sand and fine-grained gravel, underlain by at least 10 feet of cross-laminated, fine-grained sand. At Dewart (m.141) the deposit (Table 40, p. 104) consists of alternating layers of fine-grained sand and valley train gravel. At the surface there is a 4-foot deposit of fine-grained sand containing a few scattered pebbles about an inch in diameter. It is underlain by a deposit of valley train gravel consisting of pebbles 1 to 2 inches in diameter. The pebble sample recorded in Table 3 (p. 18) was taken from this gravel bed. The gravel, which here is 2 feet thick, dies out before reaching the terrace edge 400 feet away. At the base there is a deposit, 3 feet of which is exposed, which

TABLE 40. *Composite Geologic Section in Road Cut and Sand Pit, ¼ mile west of Dewart, Milton, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Sand, *Olean,* buff, fine-grained, pebbly, oxidized, non-calcareous	4	0
2.	Gravel, *Olean,* buff, medium-grained, oxidized, non-calcareous	2	0
3.	Sand, *Olean,* buff, fine-grained, poorly stratified, oxidized, non-calcareous, contains scattered pebbles	4	0
4.	Sand and silty sand, *Olean,* buff, in alternating layers 1 to 2 inches thick, oxidized, non-calcareous, contains scattered pebbles. To base	3	0
	Total	13	0

Non-calcareous
Depth of oxidation: at least 13 feet

consists of alternating sand and silty sand layers, 1 to 2 inches thick. A sample taken from this gravel contained pebbles from the following formations which are exposed only outside the Olean glacial boundary in this part of Pennsylvania:

LITHOLOGY	FORMATION	AGE	PER CENT
1. quartzite, red	Juniata	Ordovician	0.6
2. quartzite, white	Tuscarora	Silurian	2.5
3. shale, olive-green	Clinton-Wills Creek	Silurian	6.9
4. sandstone, white	Oriskany (Ridgeley	Devonian	6.3
5. chert, black	Oriskany (Shriver)	Devonian	0.6
6. shale, black	Hamilton-Marcellus	Devonian	4.6
		Total	21.5

Of the remainder, 73.3 per cent of the pebbles were derived from Upper Devonian and Lower Mississippian rocks which lie north of and behind the Olean glacial boundary. This roughly indicates the amount of contamination by non-glacial gravels, within 17 miles of the glacial boundary, to which the glacial outwash gravels were subjected.

The Illinoian terraces consist of medium- to fine-grained, red to reddish-brown valley train gravel. The gravel is usually overlain by weathered sand and silt. A cellar hole above the right bank of Turkey Run (m.148), 64 feet above the river or at 525 feet above sea level, exposed (Table 42, p. 104) about 2 feet of weathered, pebbly, medium- to fine-grained sand or medium- to coarse-grained gravel, overlain by about 2 feet of weathered silt. A zone 10 to 12 inches thick, stained black with manganese, lies about 2 feet below the surface and extends across both the sand and gravel. Aside from this zone the deposits are predominantly brown to reddish-brown in color.

TABLE 42. *Geologic Section in Cellarhole near crest of terrace 64 feet above West Branch of Susquehanna River on right bank of Turkey Run, 1 mile west-southwest of Muncy, Milton, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loam, brownish-gray, loose, silty	0	5
2.	Silt, *Illinoian,* brown to reddish-brown, clayey, contains pebbles. May be Illinoian loess	1	5
3.	Sand, *Illinoian,* black, pebbly. Composed of pebbles, 1 inch in diameter, coated with black stain in a matrix of medium sand, reddish-brown with black streaks. Grades horizontally into medium-to-coarse gravel	0	10
4.	Sand, *Illinoian,* brown, fine-grained, clayey, with red, black and gray streaks. Grades horizontally into medium-to-coarse gravel. To base	1	2
	Total	3	10

TABLE 41. *Terraces of the West Branch, Susquehanna River*

All measurements taken from plane table map by Moore and Hallock unless otherwise indicated

Miles from Mouth	Place	Bank	Terrace	Height	Width	Remarks
195	Dunnstown	left	Illinoian	65	355	Illinoian gravel.
				90	250	Covered with rubble, probably a pre-Illinoian rock bench.
190	Lock Haven	right	Binghamton	23	3100	Rises to 27 feet.
187	McElhattan	right	Binghamton	22	320	
			periglacial alluvial fan probably Olean	42	4000	Lower edge of alluvial fan which rises on slope of 1°. Described by Williams (1917) and Leverett (1934).
185	McElhattan	left	Binghamton	22	500	
181	Avis	left	Binghamton	23	1200	Covered with sand or silt.
			Olean	45	1500	Wisconsin gravel in bar along Pine Creek. Outwash from Pine Creek.
			Illinoian	67	4300	Split by creek 30 feet deep. Illinoian gravel. Reported by Leverett (1934) on east side of Pine Creek.
181	Avis	right	Binghamton	23	1200	
178	Antes Fort	right	Binghamton	25	1100	
			Olean	45	3255	
				105	1700	Rock covered with veneer of very weathered pre-Wisconsin gravel. Described by Williams and Leverett.
174	Larrys Creek	left	Binghamton	35	650	
155	Fairfield	left	Recent	15	520	Occurs along the south side of town. Moshannon loam.
			Valley Heads	24	1425	Moshannon fine sandy loam.
			Olean	41	650	15-foot gravel exposed. Wheeling fine sandy loam.
150	Muncy	right	Valley Heads	20	250	Moshannon fine sandy loam.
			Binghamton	33	1250	Wheeling fine sandy loam.
			Illinoian	60	250	12 feet of Illinoian gravel overlain by 3 feet of sand exposed. Wheeling loam.
				80	2500	Wheeling loam.
150	Muncy	left	Mankato	15	1500	Moshannon fine sandy loam.
149	Muncy Station	right	Mankato	10	250	Moshannon fine sandy loam.
			Valley Heads	13	1750	Moshannon fine sandy loam.
			Binghamton	35	535	Wheeling fine sandy loam.
			Illinoian	55	2800	12 feet of Illinoian gravel overlain by 5 feet of sand and locally overlain by 2 to 5 feet of pebbly silt. Wheeling loam.
				53	750	Wheeling loam.
147	2 miles east of Montgomery	right	Mankato	15	425	Moshannon fine sandy loam. Hand-level profile.
			Valley Heads	21	250	Wheeling fine sandy loam.
			Olean	43	550	Wheeling loam.
144	1 mile south of Montgomery	left	Mankato	15	350	
			Binghamton	30	500	
			Olean	43	300	
141	Dewart	left	Mankato	12	142	Hand-level profile. Not covered by flood of March, 1936.
			Valley Heads	23	350	This is the 20-foot terrace of White (1883).
			Binghamton	35	1000	Sand and gravel overlain by silt and sand. This is the 40-foot terrace of White (1883).
				55	100	
138	White Deer	right	Valley Heads	23	750	Sand.
			Binghamton	31	500	
			Olean	42	700	
			Illinoian	60	750	18 feet of Illinoian gravel overlain by sand and silt.
136	New Columbia	right	Valley Heads	17	85	Hand-level profile.
			Binghamton	35	500	
			Olean	50	255	
			Illinoian	75	160	Covered with till or rubble.
				91	200	Rock bench covered with silt.
134	Milton	left	Valley Heads	15	255	
			Binghamton	25	150	
			Olean	35	140	
131	Lewisburg	right	Mankato	15	300	Silt.
			Valley Heads	19	600	Silt.
			Binghamton	26	2500	
			Olean	40	800	Fine-grained gravel.
			Illinoian	60	1100	Silty soil containing cobbles, lying on rock bench.
131	Montandon	left	Valley Heads	14		Silt.
			Binghamton	35	900	Gravel.
			Olean	41	400	Dune sand over gravel.
				60		Dune sand, probably lies on Illinoian terrace.
127	Winfield	right	Binghamton	30	900	
				82	500	Rock bench at spur.
124	Northumberland	left	Binghamton	27	1200	This is the First terrace of White (1883).
			Illinoian	78	300 to 900	14-foot Illinoian gravel lying on rock bench 54 feet above river. This is the 80-foot (Third) terrace of White (1883).

The remnants of the different levels of valley fill which formed during Wisconsin time are sufficiently numerous and well preserved to permit a detailed study. The Olean terrace near Montoursville (m.157) is the composite product of outwash from Loyalsock Creek (m.157) and outwash which had entered the West Branch from Lycoming Creek (m.163) and Pine Creek (m.180) further upstream. The outwash from Loyalsock Creek filled that valley to a depth of 30 feet. This outwash, because of a sharp drop in the gradient of Loyalsock Creek near its mouth, extended out into the valley of the West Branch as an alluvial fan about 20 feet above the level of the Olean outwash terrace. The fan disappears below the level of the outwash terrace within 4 or 5 miles. One might suppose that the development of this fan across the valley of the West Branch would have resulted in a ponding of the waters of that stream. No evidence, in the form of silt or clay deposits, has been found to support such an assumption, and it is therefore necessary to suppose that the period of fan development was short and its deposits across the West Branch were washed out before extensive lake deposits could be formed or the valley fill be built up to the level of the fan.

A similar fan was formed at the mouth of Muncy Creek (m.150) by the outwash from both Muncy and Little Muncy Creeks. The alluvial fans of both Loyalsock and Muncy Creeks were dissected by floods which occurred throughout the Olean sub-stage and the Olean valley fill was developed to the level of the present Olean terraces. The surface of this valley fill, as may be seen from the profile in Figure 35 (p. 98), was little influenced by the break in stream grade west of Muncy. This may have been the result of the concentrated alluviation of Loyalsock and Muncy Creeks near this point and the accumulation of valley fill to the point that it completely masked the effects of the original stream grade.

The divergence of younger from older terraces is shown near Montoursville and Montgomery. Near Montoursville (m.157) the Binghamton terrace occurs as a series of gravel bars which rise about 6 or 8 feet above the surrounding terrace, or to an elevation of 507 feet above sea level. The surface of these bars has a very gentle downstream slope. Downstream from the nickpoint the river and the Valley Heads terrace profile draw away from the level of the Binghamton terraces until, one mile above Muncy, the Binghamton terraces are 25 feet above the river. Here the Binghamton terraces appear to fall rapidly to a point a mile below Muncy, where they are 15 feet above the river. Further downstream the profile diverges from the river grade and the terraces assume heights of about 25 feet.

The Valley Heads terrace is the lowest terrace recognized along the river above Montgomery (m.145). Unlike the older terraces, it was not subjected to severe scouring during the interstadial periods which followed. It is supposed, therefore, that the floods which occurred during the Mankato sub-stage filled the valley up to or even above the level of the Valley Heads fill. Also the floods of the present extend over this terrace. In this part of the river, then, the Valley Heads terraces are composite terraces and presumably contain the deposits of

Valley Heads and Mankato sub-stages and modern floodplain deposits. These various deposits have not been differentiated.

Near Montoursville (m.157) this terrace lies at nearly the same elevation as the Binghamton terrace, and the two terraces are separated with difficulty. At the nickpoint, 4 miles downstream, the Valley Heads profile, as is shown in Figure 35, (p. 98), parallels that of the river and draws away from the Binghamton terraces.

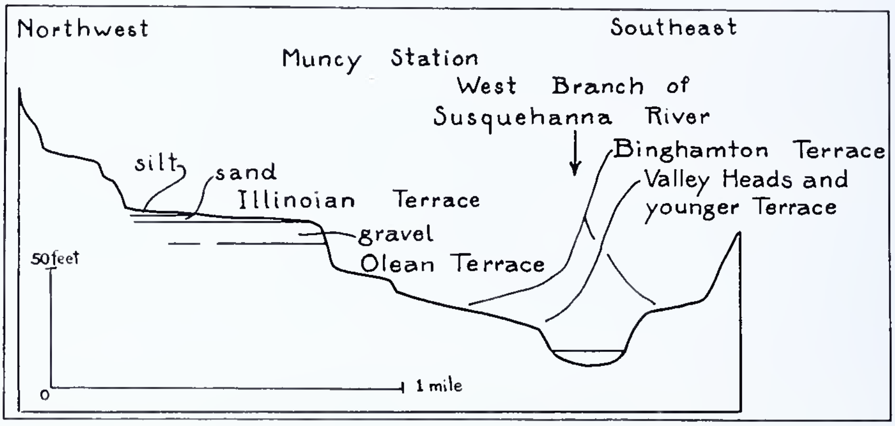

FIGURE 37. Cross-section of West Branch, Susquehanna River at Muncy (m.150) showing terraces.

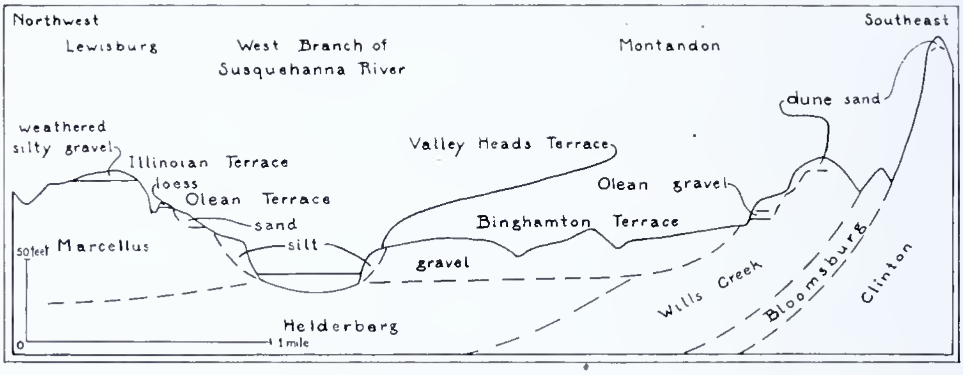

FIGURE 38. Cross-section of West Branch, Susquehanna River at Lewisburg (m.130) showing terraces.

Somewhere in the vicinity of Muncy the profile of a younger terrace begins to split away from that of the Valley Heads terraces. The terraces of this younger series first appear as distinct topographic features near Dewart (m.141). This terrace is correlated with the Mankato terrace on the North Branch.

At the upstream side of this nickpoint each terrace is drawn down toward the river grade. Each successively older group of terraces maintains its upstream profile for a greater distance past the nickpoint before dropping to a lower level. The youngest terrace, which apparently starts here, appears below the nickpoint and diverges gradually from the next older terrace. Upstream from this point the lowest terraces are the composite product of two glacial sub-stages.

Lewisburg.

At Lewisburg (m.130) the terraces described at Muncy occur under more normal circumstances and their relationship (figs. 12 and 38, pp. 50 and 106) to rock benches and deposits of dune sand may be determined.

The Mankato sub-stage is represented by a small terrace, 11 feet above the river, at the mouth of Buffalo Creek. It is composed of tan-colored, clayey silt containing fine-grained sand. The Valley Heads terrace, which lies about 20 feet above the river, is also composed chiefly of silt, but this terrace is not as frequently covered by floods and the surface soil appears to be slightly less clayey. The Binghamton terrace, which is not now covered by floods, is (fig. 38, p. 106) underlain by at least 15 feet of medium-grained gravel. This gravel was probably derived in large part from the erosion of Olean outwash deposits.

An Olean deposit of buff-colored, stratified, coarse-grained sand and silt, 8 feet thick (fig. 36, p. 102), occurs on the right bank of the West Branch ½ mile north of Lewisburg. The base of this deposit is about 37 feet above the river and it appears to lie on a narrow rock bench. On the left bank, one mile south of Montandon (m.130), a thin deposit of Olean gravel (fig. 38, p. 106) is exposed. It lies over rock which crops out 32 feet above the river and is overlain by dune sand. This dune sand, described on page 49, has not been found on the Binghamton terrace or any of the younger terraces and must, therefore, have been deposited between the time when floods abandoned the Olean surface and the time they abandoned the Binghamton surface. Presumably they are of Binghamton age. However, it is likely that sand deposited during earlier glaciations may also be present.

If any Illinoian gravel deposits occur along the left bank near Montandon, they must lie beneath these dune sands. However, on the right bank, one mile north of Lewisburg and 60 feet above the river, there is a deposit about 5 to 8 feet thick which consists of brown silt or fine-grained sand containing weathered, rounded cobbles. This deposit lies upon the beveled surface of black Marcellus shale.

Three small but distinct rock benches occur along the left bank of the West Branch at Lewisburg. The highest of these is covered in places with Illinoian deposits. It lies 90 feet above the river or at 518 feet above sea level and is at the correct elevation to form part of the Somerville peneplain as defined by Ashley (1933). Below this, at about 40 feet above the river, are the narrow remnants of a brief post-Somerville cycle. The remnants occur as rock benches covered with Olean sand, 37 feet above the river. They also occur as rock benches cut in the shale and sandstone of the Wills Creek and Bloomsburg formations one mile south of Lewisburg. Here a terrace 40 feet high and about 300 feet wide is found. At this same place there is a rock bench, 2 to 3 feet above the river, cut in Bloomsburg shale. It is about 10 feet wide and its surface is fresh. This lower bench is probably the product of current process.

TERRACES OF THE MAIN SUSQUEHANNNA RIVER

DESCRIPTION OF VALLEY

From the junction of the North and West Branches at Northumberland (m.123, or 2 miles above Sunbury) to its mouth at Havre de Grace, Maryland, near the head of Chesapeake Bay, the Susquehanna River flows across three topographic zones: a zone of narrow mountains separated by hilly valleys, a broad lowland of rolling hills, and a rolling upland into which the rivers have cut narrow, steep-sided valleys.

Throughout the upper part of its course, from Northumberland to Fort Hunter (m.74), the river flows southward in a narrow valley above which the hills rise sharply for 200 to 250 feet to a rolling upland. At the mouth of each of the larger tributary creeks the valley is broader and the slope of the valley walls more gentle. Nearly all of the terrace remnants occur in these places. Between Northumberland and Liverpool (m.98), hills 350 to 450 feet high extend to the river. Above the hills the long, narrow mountains rise 700 to 900 feet above the river. These ridges trend eastnortheasterly and are crossed by the river in a series of five narrow watergaps.

There are four breaks in the stream gradient, shown in Figure 39 (p. 108), in this section of the river. One, near Sunbury (m.121) at about 420 feet above sea level, may be due to the confluence of waters of the two branches of the Susquehanna. The others, at McKee Half Falls (m.106) at 396 feet above sea level, Mt. Patrick (m.95) at 370 feet above sea level, and at Dauphin (m.77) at 316 feet above sea level, may have been caused by the resistant rocks of Hooflander, Berry and Second Mountains respectively.

The broad valley between Blue Mountain (m.75) at Fort Hunter and Chickies Ridge (m.44) at Marietta is underlain by limestone and shale in two zones separated by diabase ridges and clastic sediments

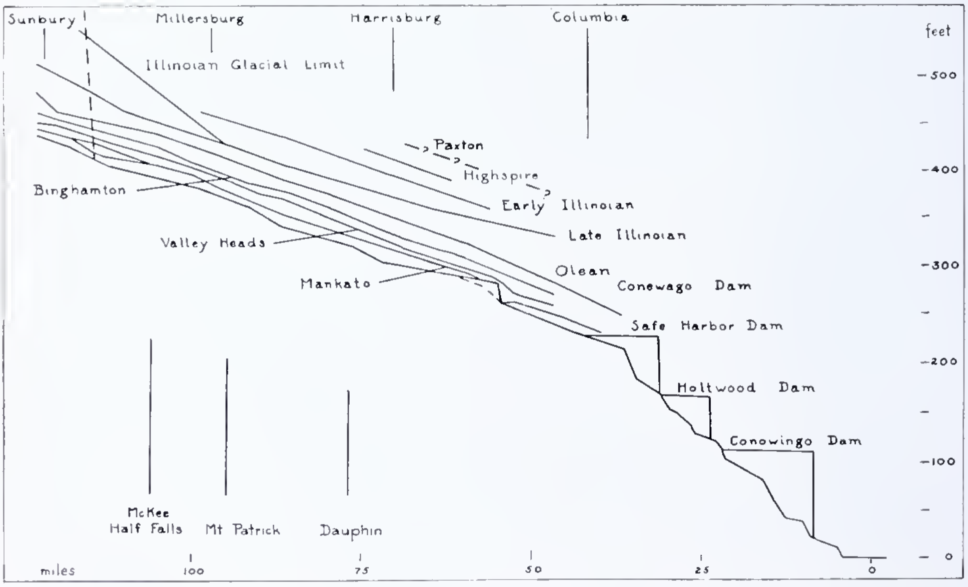

FIGURE 39. Profile of grades of the several terrace systems on the Susquehanna River between Northumberland (m.123) and Marietta (m.44).

of the Triassic belt. Terraces are well preserved here and were recognized up to 130 feet above the river. The hilltop elevations fall into three distinct groups: a lower, at a height of about 150 feet; a middle, at about 250 feet; and an upper at 400 to 500 feet.

One prominent break in the grade line occurs in this section of the river. It is Conewago Falls (m.55) at 272 feet above sea level. Its location coincides with an outcrop of diabase and, as was indicated by Mackin (1934), the falls owe their position to this resistant rock.

Below Chickies Ridge (m.44) the river enters a narrow valley, cut below the general level of the Piedmont, in which it falls rapidly 228 feet to sea level near Chesapeake Bay. Terrace remnants here are few and poorly preserved, partly because of the presence of three large dams. No attempt was made to carry the terrace correlation along this part of the valley.

TERRACES

General Statement.

The terrace profiles along the main Susquehanna River are continuous with those of the North and West Branches. In general, the terraces are lower and their gravel deposits thinner than along the North Branch. As explained on page 82, this relationship is the result of a decrease in the volume of water and gravel, which moved along the valley, downstream from the glacial boundary.

The stream grade and the grade of the terrace profiles are irregular. Nickpoints cause an irregular variation in the height of the terraces. The stream is followed by two or more rock benches whose gradient has not been determined. In some instances these benches lie near the level of gravel terraces, and thus an element of uncertainty is introduced into a purely geomorphic correlation.

Downstream from the terminal deposit of Illinoian till and gravel at Selinsgrove (m.116) there are terraces which, by the similarity of their weathering and by correlation with the terraces along the West Branch, are considered to be Illinoian in age. Above these lie other terraces, the lowest of which was called "Illinoian" by Leverett and is here considered to be Early Illinoian. A still higher gravel terrace is here called the Highspire terrace. It lies along the east side of the river near Harrisburg. This terrace contains granite pebbles which could only have reached this location as outwash of a glaciation which brought materials over the present divide of the Susquehanna drainage. It is probably Kansan in age.

Mankato Terraces.

Narrow terraces of sand and silt, presumably of Mankato age, occur along the valley at an average height of 10 feet. They are everywhere overtopped by modern floods and are therefore probably composite terraces containing the deposits of both Mankato and Recent age. These components have not been distinguished at any locality, and the presumption that the main portion of these terraces is Mankato is based on evidence obtained on the North Branch (p. 79).

Valley Heads Terraces.

The Valley Heads terraces occur at an average height of 19 feet above the river. Along the river above Conewago Falls (m.55) they lie between 2 and 5 feet above the crestline of the flood of March 1936, and they probably contain no deposits of modern floods. There is a general tendency, obscured by changes in height related to the more abrupt changes in bed-rock grade, for the terraces to decrease in height downstream from Falls (m.203) on the North Branch, where they are about 25 feet high, to Highspire (m.62), where they are about 15 feet high. This decrease in height, which is paralleled by the Binghamton and Olean terraces, is probably the result of a downstream decrease in the quantity of alluvium carried by the stream and a downstream decrease in the height of the flood grades during deposition.

Binghamton Terraces.

The Binghamton terraces are the broadest and best preserved of the Pleistocene terraces along the Susquehanna River. They are composed of medium-grained gravel containing granite and other pebbles, which must have been derived from sources outside of Pennsylvania. Most of the pebbles, however, were derived from local rocks outcropping in the watershed of the river south of the Binghamton glacial boundary. In general, the terraces of this sub-stage are 29 feet above the river and tend to decrease in height toward the mouth of the river. At West Pittston (m.192) the Binghamton terrace is 45 feet high, at Danville (m.134) it is 30 feet high, and at Highspire (m. 62) it is only 18 feet high. Near Harrisburg (m.70) the Binghamton terraces appear to merge with the Valley Heads terraces or become buried by them, for below Conewago Falls (m.55) the terraces fall into a single grade line, with which the Binghamton and Valley Heads grades of the upper part of the river merge.

Olean Terraces.

The Olean sub-stage is poorly represented along the main Susquehanna River. The greater part of its deposits were either washed away or buried during Binghamton time. Remnants of the Olean valley fill appear chiefly as gravel ridges which rise above the level of the Binghamton terraces, or in rock-defended positions where the gravel has been protected against lateral cutting by the river. The Olean remnants have an average height of 45 feet. Like the terraces of the Valley Heads and Binghamton sub-stages, they tend to decrease in elevation downstream. The Olean terraces vary from a height of 50 feet at Berwick (m.159), on the North Branch, to 45 feet at the mouth of the Juniata River (m.84) and 36 feet at Highspire (m.62).

This decrease in the height of the glacial outwash terraces, at a rate of 2 or 3 inches per mile, is related to the quantity of sand and gravel which was available to the river at the time the valley fill was deposited. It is not directly related to the distance which a terrace lies from the glacial limits of the stage or sub-stage during which it was deposited, for at their respective ice boundaries the Binghamton terrace is 46 feet high, the Olean terrace is 50 feet high, and the Illinoian terrace is 63 feet high. Furthermore, the terrace profiles do not decrease in height at a uniform rate but at one which varies directly with age. The older terraces decrease in elevation more rapidly than the younger ones. The downstream decrease in the height of the terraces and the distance from their source are not, alone, adequate to explain the difference in height between the terraces of different ages. It must be assumed that there is some lowering of the bed-rock channel in this stretch of the river. However, as shown on page 115, the lowering in post-Illinoian time is limited to 20 feet. Thus the difference in height may be explained by assuming that the Susquehanna River lowered its bed by 10 or 12 feet between the Illinoian and Wisconsin stages and by about 5 feet between the Olean and Binghamton sub-stages. The valley fill of each stage or sub-stage would then have formed to the same depth and the gradient of that fill would become smaller with each successive sub-stage as the volume of previously deposited gravels became greater.

Illinoian Terraces.

The Illinoian terraces, south of the Illinoian "moraine" at Selinsgrove (m.116), appear to fall into two separate terrace systems. The Lower or Late Illinoian terraces lie about 20 feet below the Higher or Early Illinoian terrraces. The terraces traced by Leverett (1934) were these of the higher system. The Late Illinoian valley fill is represented by scattered, poorly preserved remnants on the valley walls between 50 and 75 feet above the river. From Northumberland (m.123) to Conewago Falls (m.55) the profile of these remnants (fig. 39, p. 108) is essentially parallel to the profiles of the younger terraces and lies 15 to 20 feet above the Olean profile. No break in slope, such as occurs in the Wisconsin terrace profiles, occurs in the Late Illinoian profile at Conewago Falls. The Late Illinoian terrace gravels continue to occur along the same grade line for 10 miles beyond the falls. Probably Conewago Falls retreated from Chickies Rock (m.44) to near its present position during the Illinoian-Olean interglacial interval.

No evidence of an unconformity between the gravels of the Early and Late Illinoian terrace deposits was found at any locality. However, as has already been shown, one and only one terrace was formed during any sub-stage of the Wisconsin. If it is supposed that this was also true of the Illinoian glacial stage, the two Illinoian terraces are the alluvial deposits of two, distinct, glacial sub-stages.

Pre-Illinoian Terraces.

A few bodies of pre-Illinoian gravel, whose elevation and character indicate a Pleistocene age, are found between New Buffalo (m.87) and Craigtown, Maryland (m.2). These gravels lie between 70 and 135 feet above the river. They have been previously recognized by Wright (1892), Bashore (1894), Stose (1928), Leverett (1934), and others. In a few places, such as near Harrisburg (m. 69), described on page 118, these gravels lie upon easily recognized rock benches and it is apparent that the gravels are divisible into the deposits of at least two or three different ages. The name "Highspire terrace" is here applied to the terrace which occurs 1½ miles northwest of Highspire (m.62) at a height of 110 feet above the river or 400 feet above sea level. It is underlain by limestone. The higher terrace, which Wright (1892) called the "130-foot terrace", is here called the 'Paxton terrace". It lies along the left bank of Paxton Creek at Harrisburg (m.70) at a height of 130 feet or 430 feet above sea level. These bodies of gravel are, however, too few in number to be analyzed into grade lines, and their significance can be discovered only through extensive field work involving the area downstream from Marietta (m.44).

Rock Benches.

Rock benches which represent at least two sub-cycles of erosion occur along the Susquehanna River below the remnants of the Harrisburg partial peneplain. A sufficient number of these remnants has not been found to permit an accurate reconstruction of the valley profile during each of these sub-cycles.

The profile of the Harrisburg benches has an average gradient of about 1.7 feet per mile. A bench of this sub-cycle occurs at Northumberland (m.123), where it was described by White (1884) as the "fourth terrace": a narrow shelf, 175 feet above the river or at 605 feet above sea level. At Millersburg (m.96), it was previously identified and described by Barrell (1920), Fridley (1929) and Ver Steeg (1930). Here it is 160 feet above the river or 545 feet above sea level. At Harrisburg (m.69) it is 210 feet above the river or at 510 feet above sea level.

The benches which lie about 90 feet below those of the Harrisburg sub-cycle have been previously correlated with the Somerville sub-cycle by Ashley (1933). Their profile appears to slope at an average gradient of about 1.9 feet per mile. At Sunbury (m.122) one of these benches lies 80 feet above the river or at 505 feet above sea level. At Millersburg two Somerville benches lie 95 feet above the river or at 465 feet above sea level, and at Harrisburg a Somerville bench is 86 feet above the river or at 380 feet above sea level.

Other rock benches lie below those of Somerville age. Above Half Falls (m.92) there are, apparently, only the rock benches of a single sub-cycle. They occur about 40 to 50 feet above the river and their profile parallels the stream grade at about 2.1 feet per mile. Along this part of the river these terraces do not, then, appear to rise above the stream grade as do the older terraces. The sub-cycle which formed these benches occurred (p. 114) at some time before the Illinoian glaciation. Below Half Falls there is some evidence that there is a still younger series of rock benches which, above Conewago Falls (m.55), are only about 15 to 20 feet above the river, but which extend below Conewago Falls at higher levels.

The significance of these rock benches can be determined only after an extensive study of the Susquehanna River below Marietta (m.44). It is, however, apparent (as is shown on page 115) that an erosional sub-cycle intervened between the completion of the Somerville sub-cycle and the advance of the Illinoian ice.

SELECTED LOCALITIES

Selinsgrove.

Near Selinsgrove (m.116), at the mouths of Penns and Middle Creeks, the valley is relatively broad and terraces are well preserved. Here the Pleistocene terraces (fig. 40, p. 113) may be observed in relation to the remnants of the Illinoian "terminal moraine" and to the rock benches which also lie along the river. It may be demonstrated, at this locality, that the Somerville rock bench is distinctly older than Illinoian and that the Susquehanna River has not lowered its bed, here, by more than 20 feet since Illinoian time.

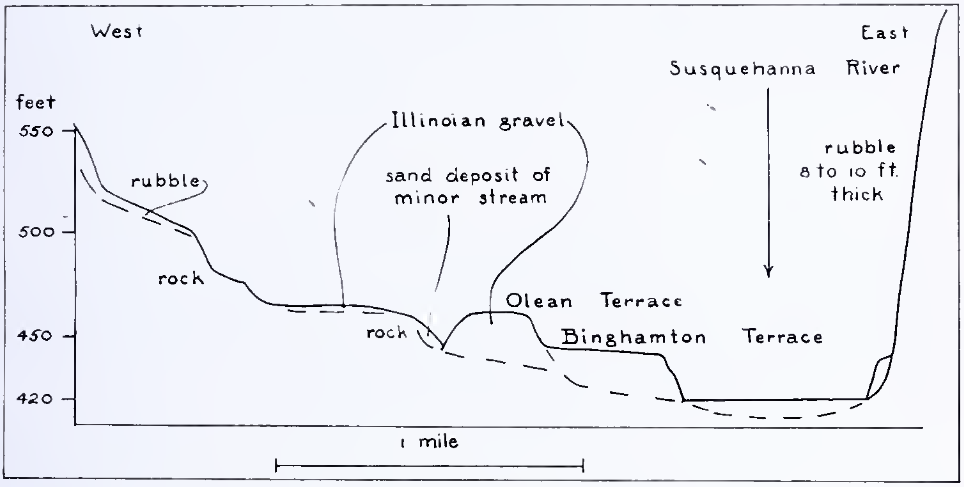

FIGURE 40. Cross-section of Susquehanna River (m.118) near Selinsgrove showing terraces.

The Mankato valley fill is represented, near Selinsgrove, by narrow terraces, now covered by modern floods, which lie along Penns Creek and along the Susquehanna River near the mouth of Penns Creek (m.113) about 12 feet above the river. The Valley Heads terraces are 18 to 22 feet above the river. They are also narrow but are different from the Mankato terraces, for they are 4 or 5 feet above the level of the 1936 flood at their lowest points.

The Binghamton sub-stage is represented by a terrace in the form of a bar which extends along the right bank of the Susquehanna for 3 miles above the mouth of Penns Creek. This bar, and the younger deposits which have accumulated at its lower end, have diverted Penns Creek near its mouth, causing that creek to parallel the Susquehanna River, at a distance of only 2000 feet, for 4 miles. Similar diversions of tributary creeks occurred at Sunbury (m.121) and Harrisburg (m.70). The gravel deposited at this time is exposed in a gravel pit 1 mile south of Selinsgrove (m.116). This deposit (Table 43, p. 114) contains no well developed soil. At the surface, 29 feet above the river, there is a layer of silty gravel, 2 feet thick. This layer is probably the product of the infiltration into the gravel of silt deposited on the surface. Oxidation has progressed to a depth of 9 feet. The pebbles found here (Table 3, p. 18) are composed almost entirely of local rocks. However, the presence of pink granite, shown in Table 6 (p. 20), and coal,

TABLE 43. *Geologic Section in Gravel Pit on interfluve between Penns Creek and Susquehanna River, 1 mile south of Selinsgrove, Sunbury, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	THICKNESS inches
1.	Loam, black, silty	0	2
2.	Gravel, *Binghomton*, buff, loose, silty, oxidized, structureless	2	0
3.	Gravel *Binghomton*, brown to tan, sandy, oxidized, cross-bedded	7	0
4.	Gravel, *Binghomton*, gray, sandy, non-calcareous, unoxidized, cross-bedded. To base	12	0
	Total	21	2

Non-calcareous
Depth of oxidation: 9 feet

not found in West Branch gravels, indicates that a significant part of this gravel came from the North Branch. The shallow depth of oxidation and soil development, however, indicates that this deposit is younger than Olean in age and its elevation above the river indicates that it is older than Valley Heads.

Other Binghamton terraces (Table 44, p. 116) occur along the right bank of the river above Selinsgrove at heights of from 25 to 30 feet.

Terraces of Olean age occur along Penns Creek at a height of about 45 feet above the Susquehanna River. The deposits of Olean gravel, which now remain, appear to be small and in some places the surface of the Olean terrace, (fig. 40, p. 113) is underlain by Illinoian till or gravel. Such a terrace must have been formed by the lateral erosion of the Illinoian deposits by the Olean floodwaters.

Small remnants of the Illinoian outwash plain occur along the right bank 3 miles north of Selinsgrove and at Selinsgrove. They occur as rounded and eroded terraces and hills of gravel about 65 to 70 feet above the river. In some instances the erosion has been so severe that the terrace form has been lost and a body of Illinoian gravel in the hillside is all that remains. Higher deposits of Illinoian gravel, described on pages 28 to 30, (fig. 7, p. 29), occur up to 145 feet above the river. They were presumably laid down as ice-contact deposits. These gravels (Table 3, p. 18) consist entirely of pebbles derived from local rocks. No granite pebbles, such as are found in the Illinoian gravels further downstream (Table 3, p. 18), occur here. In this respect the gravel resembles that of the West Branch instead of that of the North Branch, and it is supposed that this gravel was deposited in contact with a body of ice which had moved along the West Branch.

As is shown in Figures 7 (p. 29) and 41 (p. 115), the bed-rock topography which is buried by the Illinoian glacial deposits is irregular. It has a relief of at least 125 feet. Several rock benches are included in this buried topography and, where they are exposed or are near the surface, complicate the correlation of the terraces. Rock benches, supposed to have been cut during Somerville time, occur on the valley walls north and west of Selinsgrove at heights of 90 to 100 feet above the river or at about 520 feet above sea level. A lower group of rock benches nearly coincide in elevation with the Olean outwash terraces, for they are about 45 feet above the river or about 455 feet above sea level. They are overlain by Illinoian till or gravel or by rubble. This bench may be seen along the west side of U. S. Highway 11, ½ mile north of Port Trevorton (m.111). Here an old cut in the face of the terrace shows 10 or 12 feet of Illinoian valley train gravel lying upon a rock bench. The top of this bench is 44 feet above the river or 442 feet above sea level. The outwash terrace is (Table 44, p. 116) 56 feet high and 75 feet wide.

Other, still lower, rock benches occur about 22 feet above the Susquehanna River near Selinsgrove. One of these may be seen 4 miles south of Selinsgrove on the right bank of the Susquehanna River, and another (fig. 41, p. 115) 1 mile north of Selinsgrove on the right bank of Penns Creek. The bench on Penns Creek is cut in black slate. It is 10 feet above the creek, or 439 feet above sea level. This bench is overlain by 23 feet of coarse-grained, sticky, weathered, red, Illinoian gravel. Like the rock bench at Port Trevorton, 6 miles downstream, it is distinctly older than Illinoian in age. One must, therefore, suppose that the Somerville surface was dissected to a depth of at least 60 feet and a lower rock surface formed before the Illinoian glaciation. It is equally apparent that the Susquehanna River has not cut down into its channel by more than 20 feet in post-Illinoian time.

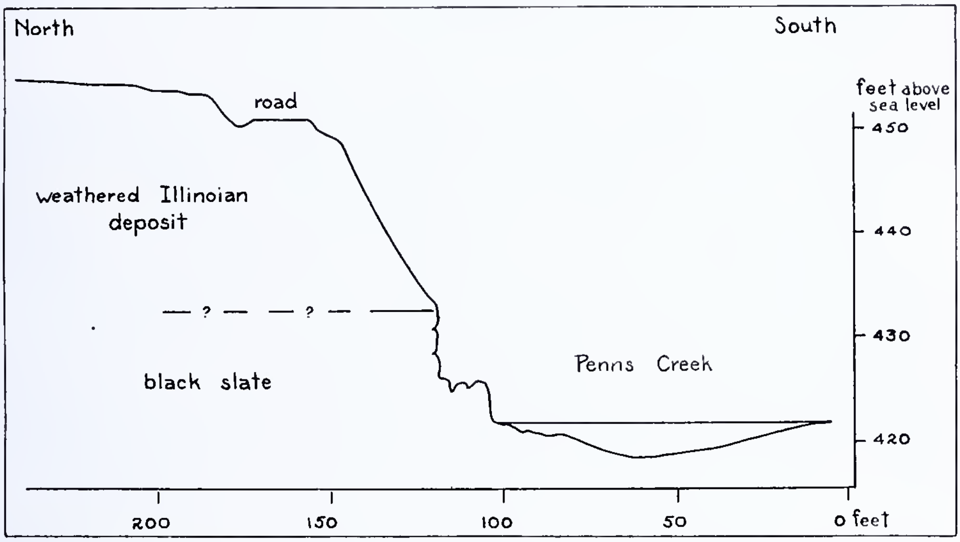

Figure 41. Diagram of right bank of Penns Creek near Selinsgrove showing relationship between Illinoian deposit and bed rock.

Harrisburg.

Along the Susquehanna River between Harrisburg (m.69) and Marietta (m.44) the terraces have been previously studied by Wright (1892), Bashore (1894), Stose (1928), Mackin (1934, 1936), Leverett (1934) and others, and it is possible to relate the glacial chronology of the terraces with the chronology previously proposed in relation to the terraces of the Coastal Plain. No previously unrecognized terraces were found along this part of the river.

The terraces here differ from those upstream in that, although composed mainly of gravel, they are usually overlain by 5 to 10 feet of silt. This silt is laminated in places and therefore was deposited by floods, but some unlaminated silts occur and resemble the loess deposits 100 miles upstream. They may have been blown from the contemporary or some later river bed to their present position.

The Mankato terrace occurs at Harrisburg as a swale, ½ mile to a mile from the river, occupied by Paxton Creek. The creek parallels the Susquehanna River for 5 miles above its mouth. Here the plain of the creek is 17 feet above the river level and about 2000 feet wide. Near its mouth the creek valley falls to a lower level and is entrenched 5 to 8 feet below the level of this surface. This relationship indicates that, although the plain of Paxton Creek lies at or below the level of the 1936 flood, it is older than Recent and that the creek has already begun to lower its bed in adjustment to a lower grade line.

At the downstream side of Conewago Falls (m.54) a terrace, presumed to be of Mankato age because of its elevation, lies along the left bank 5 feet above the river. This terrace slopes upstream at an angle of 1.3 feet per mile, so that 1½ miles below the falls it is 11 feet above the river. This reverse slope is assumed to be the response of terrace development to the hydraulic jump produced by the falls and to the downstream increase in the depth of the river which accompanied a parallel decrease in stream velocity. This was the only example of such a feature found along the Susquehanna River, but the magnitude of the change is so small that it could be detected only by survey methods such as, in this instance, were carried out by Moyer and Hickok. At Conewago Falls, within a distance of 8 miles, the profile of the Mankato terraces falls from 10 feet to 5 feet in height, then returns to its original height of 10 feet. This illustrates on a small scale the effects, at nickpoints, of a drawdown curve in the water surface upon the terrace profile. At most of the nickpoints upstream the return of the terraces to their former height was not apparent for many miles.

The effect of the drawdown curve set up by Conewago Falls is apparent in the profiles of the Valley Heads and Binghamton terraces at Harrisburg (fig. 39, p. 108). The profile of each of these terraces decreases in height above the river by about 15 feet in the 13 miles between Fort Hunter (m.75) and Highspire (m.62). Presumably, therefore, the plains which were formed during these sub-stages regained the height above the river, downstream from Conewago Falls (m.55), which they had followed above the falls. However, for 15 miles below the falls, terrace deposits which lie less than 25 or 30 feet above the

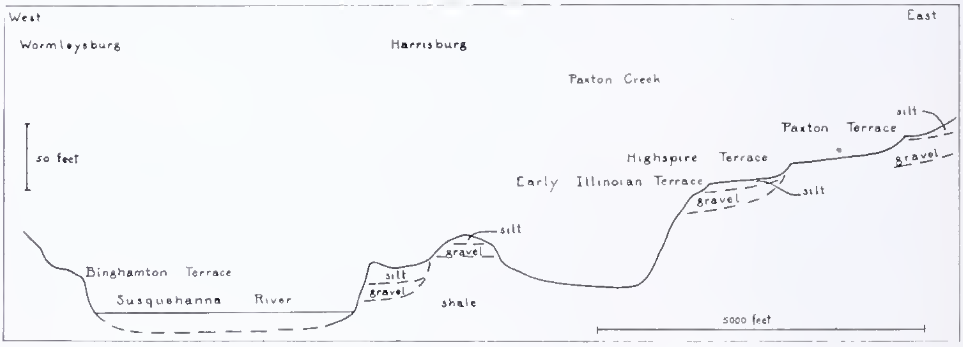

FIGURE 42. Cross-section of Susquehanna River (m.69) at Harrisburg showing terraces.

TABLE 44. *Terraces of the Main Susquehanna River.*

Miles from Mouth	Place	Bank	Terrace	Height	Width	Remarks
122	Sunbury	left	*Valley Heads*	11	700	Occurs along creek at inner edge of Binghamton terrace.
			Binghamton	25	1400	The 445-450-foot terrace of White (1883).
			Illinoian	80	1000	Rock bench on spur above Shamokin Creek. Probably the 525-foot terrace of White (1883). The 55-foot terrace of Leverett (1934).
119	Shamokin Dam	right	Binghamton	21	900	
			Olean	32	700	Terrace cut on Illinoian gravel.
			rock bench	51	700	
			Late *Illinoian*	67	1000	Rock bench strewn with cobbles, partly covered with rubble.
			rock bench	70-80	1400	
117	Selinsgrove	right	Binghamton	29	1400	25 ft. of gravel.
			Olean	43	500	
			Illinoian	71	700	A knob above the Olean terrace.
112	Mahantango Creek	left	*Mankato*	11	50	
			Valley Heads	23	250	The 22-foot terrace of Leverett (1934).
			rock bench	43	300	Rock bench on spur.
110	Port Trevorton	right	*Valley Heads*	20	230	
			Illinoian	38	75	
108	Chapman	right	*Valley Heads*	11	300	
			Binghamton	23	150	
			rock bench	70	500	
105	McKees Half Falls	right	*Valley Heads*	13	140	Abandoned canal near edge. Terrace rises gradually to 30 ft. Hand level profile.
			pre-*Illinoian*	95	140	Surface covered with fine sand.
104	Mahantango	right	*Mankato*	11	330	Abandoned canal. Hand level profile.
			Valley Heads	20	100	
			Binghamton	30	1200	Sand.
			Late *Illinoian*	55	100	Weathered gravel.
			pre-*Illinoian*	115	800	Surface strewn with fine sand and cobbles.
103	Mahantango	right	*Valley Heads*	15	300	Abandoned canal at inner edge.
			Binghamton	30	100	
			Olean (?)	40	300	Rock bench covered with silt.
			rock bench	70	1500	
101	Paxton	left	*Valley Heads*	17	1300	
			rock bench	40	700	
			rock bench	65	700	
			rock bench	75	350	
95	Liverpool	right	Binghamton	20	50	
			Olean	30	300	Gravel. This is probably the 40-ft. terrace of Leverett (1934).
				90	150	
				135	170	
94	Millersburg	right	*Mankato*	11	410	Sand.
			Binghamton	25	420	Gravel.
			rock bench	160	230	
93	Mt. Patrick	right	*Valley Heads*	15	150	
			Binghamton	25	150	
			rock bench	50	300	Covered with silt. Leverett (1934) described corresponding terrace on left bank.
92	Half Falls	left	Binghamton	25	150	
			Olean	45	350	
90	Halifax	left	Binghamton	30	430	
			Olean	90	350	
88	New Buffalo	right	*Valley Heads*	11	200	
			Illinoian	73	300	Weathered gravel on rock bench.
87	New Buffalo	right	*Valley Heads*	13	500	Abandoned canal at inner edge.
			Olean	47	150	5 ft. of silt on rock bench.
84	Haldeman Id.	right	*Valley Heads*	10	200	
			Binghamton	25	1900	
			Olean	40	700	
			Illinoian	65	2000	
80	Cove	right	*Valley Heads*	20	500	
			Binghamton	30	750	
75	Fort Hunter	left	*Recent*	8	650	
			Valley Heads	35	460	
69	Harrisburg	left	*Mankato*	11	1300	Occurs along right bank of Paxton Creek.
			Binghamton	28	1000	1st terrace of Bashore. 28-ft. terrace of Wright. Talbot terrace of Stose. Bar 3 ft. high near outer edge.
			Olean	43	300	2nd terrace of Bashore. 44-ft. terrace of Wright. Probably the 43-ft. terrace of Leverett.
			Early Illinoian	95	1000	3rd terrace of Bashore. 90-ft. terrace of Wright. 2nd gravel terrace of Stose.
			Highspire	~110	1500	Upper gravel terrace of Stose.
			Paxton	130	600	4th terrace of Bashore. 130-ft. terrace of Wright. Sunderland terrace of Stose.
67	Wormleysburg	right	Binghamton	30	300	Talbot terrace of Stose.
65	Newmarket	right	*Valley Heads*	11	500	
			Olean	50	2500	3 ft. of relief.
			Early Illinoian	75	300	2nd gravel terrace of Stose.
62	Highspire	left	*Valley Heads*	11	300	Grades without break into Binghamton terrace.
			Binghamton	21	900	Abandoned canal at inner edge.
			Olean	45	200	
			Highspire	100	300	Upper gravel of Stose.
61	Highspire	left	Mankato	10	400	
			Binghamton	30	1400	Abandoned canal at inner edge.
			Olean	41	600	
			rock bench	73	1100	
60	Middletown	left	Mankato	10	330	
			Binghamton	30	1800	Talbot terrace of Stose.
			Late Illinoian	51	1600	
			Early Illinoian (?)	80	1000	Wicomico terrace of Stose.
59	Royalton	left	*Valley Heads*	11	1300	
			Late Illinoian	30	700	
58	Falmouth	left	*Valley Heads*	10	190	
			Binghamton	21	300	
			Olean	35	750	Contains 5-10 ft. of gravel. Occurs at river's edge where Binghamton terrace is absent. 2nd gravel terrace of Stose.
			Highspire	90	1770	Rock bench.
54	Conewago Falls	left	*Valley Heads*	20	300	Elk silt loam.
			Illinoian	70	540	Contains weathered gravel, 3 ft. of relief. Elk silt loam.
48	Shocks Mills	left	Mankato	11	600	Hand level profile. Huntington fine sandy loam.
			Binghamton	30	200	Talbot of Stose. Elk fine sandy loam.
			Olean (?)	55	700	Silt on rock bench. Wicomico terrace of Stose. Probably corresponds with 50-ft. terrace of Leverett at Marietta. Elk silt loam or Elk gravelly loam.
			Late Illinoian	90	300	Silt over weathered gravel. 2nd gravel terrace of Stose. Probably corresponds with 110-ft. terrace of Leverett at Marietta. Hagerstown silt loam.
			Paxton (?)	135	300	Rock bench covered with silt. Sunderland terrace of Stose. Hagerstown silt loam.

Note: All measurements taken from surveys by Moore and Hickok unless otherwise indicated.

river are buried or obscured as the result of modern floods. The Valley Heads terrace was not observed at Harrisburg.

At Harrisburg (m.69) the Binghamton terrace (Table 44, p. 116 and fig. 42, p. 116) is 30 feet above the river or at an elevation of 327 feet above sea level, and is 1000 feet wide. This terrace was described by Wright (1892), who called it the "28-foot terrace", and by Bashore (1894), who called it the "First Terrace". Both authors described the terrace as composed of "fine brick-making clay and . . . many boulders of large size". The clay of which they wrote is probably the same material which is described here as silt. This also appears to be the terrace which Stose (1928) called the "Lowest Terrace" and which he described as 20 to 40 feet above the river and as containing "pebbles of granite and other rocks foreign to the river basin".

At Highspire (m. 61) the Binghamton terrace is an isolated, bar-shaped terrace 1500 feet wide. It is 20 feet above the river at its outer edge and rises to 27 feet near the center. The upper 7 feet of this bar (Table 45, p. 117) is composed of buff, pebble-free, compact silt. Below this are at least 9 feet of medium-grained gravels interbedded with medium- or fine-grained sand. The contact between the silt and the underlying gravel is sharp. For a depth of a foot below the contact, the gravel and sand have a slightly darker color than that which lies below, and the upper 4 inches of this horizon has a looser texture. This may be an immature soil and may indicate a short period of exposure prior to the deposition of the overlying silt. The remainder of the gravel is fresh in appearance and the presence of granite pebbles (Tables 3 and 6, pp. 18 and 20) indicates that the deposit was derived from the glacial deposits of the Adirondack lobe, described on page 21.

TABLE 45. *Geologic Section in Gravel Pit 1 mile east-southeast of Highspire on west side of Highway 230, New Cumberland, Pa., Quadrangle.*

HORIZON	DESCRIPTION	THICKNESS feet	inches
1.	Silt, *Valley Heads* (?), buff, compact, pebble-free, non-calcareous	7	0
2.	Gravel, *Binghamton*, buff, loose, medium-grained, non-calcareous	0	4
3.	Gravel, *Binghamton*, tan, compact, medium-grained in medium- to fine-grained sand matrix	1	0
4.	Gravel, *Binghamton*, buff, medium-grained in medium- to fine-grained grained sand matrix, non-calcareous	8	0
	Total	16	4

Non-calcareous
Depth of oxidation: at least 16 feet

The Olean terrace at Harrisburg rises to 48 feet, or 15 feet above the Binghamton terrace. This terrace was accurately described by Wright (1892) as the "46-foot terrace", and as composed of gravel containing granites and capped by fine loam. It was similarly described by Bashore (1894), who called it the "Second Terrace". The thickness of the surface silt deposit varies from 2 to 10 feet, and the elevation of the terrace varies, similarly, from 41 to 48 feet, or from 338 to 345 feet above sea level. This terrace was also described by Stose (1928) and called by him the "Second Gravel Terrace".

On the left bank, at Highspire (m.62), a remnant of the same age is about 500 feet wide and rises steeply 35 feet above the abandoned

Pennsylvania Canal to a height of 45 feet. This terrace is continuous and unbroken as far as Swatara Creek at Middletown (m.59), where it is 1600 feet wide and 55 feet above the river.

The Late Illinoian terrace at Harrisburg (m.69) is about 60 feet above the river or 360 feet above sea level. It occurs here as a small remnant which rises above the Olean terrace in the center of the city. This terrace lies 40 feet below the general height of the Illinoian terraces described by Leverett (1934) and belongs to a younger group of terraces. The terraces which Leverett identified as Illinoian are, as will be shown below, present at Harrisburg. The gravel which they contain resembles that of the Illinoian glacial deposits in all respects, and Leverett was probably correct in identifying them as Illinoian in age. Studies of grade lines, as shown in Figure 39 (p. 108), indicate that they belong to the Early Illinoian gravel fill.

At Shocks Mills (m.48), below Conewago Falls, the terrace, which belongs to the lower series of Illinoian terraces, is about 500 feet wide and lies 95 feet above the river. This terrace was previously identified and mapped by Leverett (1934). It is underlain, as is shown in Table 20 (p. 45), by a deposit, at least 15 feet thick, of medium-grained, weathered gravel in a red, clayey matrix, overlain by weathered, pebbly silt. The gravel lies on a bench of limestone whose elevation is 72 feet above the river or 306 feet above sea level.

The terrace, mentioned above, which Leverett identified as Illinoian, occurs at Harrisburg at an elevation of 87 feet above the river or 382 feet above sea level, and is 1000 feet wide. It may be seen on Sycamore Street, 1000 feet south of the corner of 17th Street. This terrace was described by Wright (1892), who called it the "90-foot terrace", and by Bashore (1894), who called it the "Third Terrace". Both authors described it as containing gravel with granite and gneiss pebbles and a surface mantle of fine-grained sediments. This gravel must, because of the presence of crystalline pebbles, have been derived from glacial deposits. Leverett (1934) has correctly pointed out that the terraces of this time may be traced along the Susquehanna River below Selinsgrove (m.116) and along the Juniata River. In many instances they occur directly above younger terraces of Illinoian age. As was explained on page 111, the writer is inclined to agree with Leverett's identification of this terrace as Illinoian in age, but to suggest the possibility that it may represent an earlier glacial sub-stage than that represented by the lower Illinoian terrace described on page 114. This appears to be the terrace which Stose (1928) called the "Second Gravel Terrace", giving its elevation at Harrisburg as 380 feet above sea level.

Above the Illinoian terraces at Harrisburg there is a still older bench or terrace, here called the Highspire terrace (p. 111). It is 105 to 110 feet above the river, or 405 feet above sea level, and is 1700 feet wide. This terrace, which does not appear in the earlier literature, is separated from older and younger terraces by relatively sharp rises of 15 feet. It may be seen on Herr Street, near the corner of 17th Street. This terrace may be the same rock bench which underlies the next higher terrace and which has been exposed as a result of the erosion of the gravel and weathered silt veneer.

The Paxton terrace is the oldest gravel terrace known to occur at Harrisburg. It lies above the left bank of Paxton Creek, in the northeastern part of the city, at an elevation of 125 feet above the Susquehanna River or 420 feet above sea level. Wright (1892) called this terrace the "130-foot terrace" and Bashore (1894) the "Fourth Terrace". They described exposures opened by the cutting of the streets in which there was a deposit of gravel about 20 feet thick, capped by a "fine brick clay" and underlain by bed-rock. They found the deposit thoroughly weathered and leached and they both found granite and gneiss pebbles in the gravel. These pebbles signify a glacial origin for the gravel in the deposit and provide the strongest argument that there was a pre-Illinoian glacial advance into the Susquehanna Valley.

The age of this gravel is unknown. The writer has been unable to correlate it with any body of till or deposit of gravel containing crystalline rocks. It does not appear likely that the terrace, 500 feet above sea level at Dauphin, upon which Leverett (1934) found a gneiss cobble, correlates with this terrace at Harrisburg, for it would necessitate a gradient of 11 feet per mile for the terrace. Such a gradient could be brought about either by a sharp fall in the river grade line or by the presence of an ice front. No evidence supports the assumption of either of these possibilities.

Excavations in and around Harrisburg have shown the presence of rock surfaces beneath the gravel at elevations of 110 feet, 75 feet and 40 feet, or at 405 feet, 370 feet, and 340 feet above sea level. Presumably these heights are the surfaces of rock benches. The 405-foot rock bench is probably part of the Somerville peneplain which Ashley (1933) and others have identified between 400 and 440 feet above sea level at Harrisburg. This rock bench lies buried by the glacially derived gravels of Wright's "130-foot terrace". These gravels are almost certainly as old as the Kansan glacial deposits of the Mississippi Valley. The rock bench cannot, therefore, be younger than Aftonian in age.

The rock benches, 75 and 40 feet above the river, are overlain by Illinoian glacial outwash gravel and, by similar reasoning, cannot be as young as Illinoian in age. Possibly the 75-foot bench should be correlated with the rock benches 40 to 50 feet above the river near Port Trevorton, described on page 114 (m.122), and the 40-foot bench with the 70-foot bench near Marietta (m.45), described on page 118. However, an insufficient number of exposures has been found to permit an accurate reconstruction of the grade lines.

Stose (1928) and Leverett (1934) have suggested correlations with the marine benches and coastal plain deposits of Chesapeake Bay. Stose correlated his "Second Gravel Terrace", described on page 117, with the Wicomico terrace, and his "Upper Gravel Terrace" with the Sunderland terrace. Leverett pointed out that times of high sea level, during which the coastal terraces were presumably formed, are more consistent with interglacial than with glacial times. He considered that the Wicomico shoreline was "nearest in age" to his Illinoian terrace, and that the Sunderland formation presumably bore the same relationship to pre-Illinoian deposits in the Susquehanna Valley. He was, therefore, essentially in agreement with Stose.

Before this correlation can be verified or extended, further study of the coastal terraces must be made. A greater number of terraces, which presumably represent cold periods and periods of low sea level, have been recognized in the Susquehanna Valley than have so far been recognized near Chesapeake Bay. The number of coastal plain terraces should be comparable to the number of river terraces. A reconnaissance of the head of Chesapeake Bay indicates that the Talbot, Sunderland and Brandywine formations contain benches which appear to record, in each instance, more than one sea level, or a total of at least seven levels. The presence of at least one sea level lower than the present is apparent from the U. S. Coast and Geodetic Survey map of the head of Chesapeake Bay, which shows a submerged delta near the mouth of the river. After the levels of the existing beach remnants have been established, it may be possible to determine their relationship to the climatic terraces of the Susquehanna River.

TERRACES OF THE JUNIATA RIVER

DESCRIPTION OF VALLEY

The Juniata River, throughout the 85 miles from the junction of the Raystown and Frankstown branches until it joins the Susquehanna River, flows in a narrow, meandering valley (fig., p. x). For the first 2 miles below the mouth of the Raystown Branch at Ardenheim (m.169) it flows eastsoutheastward past the northern end of Terrace Mountain, which rises steeply 1300 feet above the valley. It then turns southward and, for 3 miles, flows between Clear Ridge and Jacks Mountain. The valley walls rise steeply on both sides for about 300 feet, where there is a narrow, dissected bench, then rise again for another 200 feet to the summit of Clear Ridge and 1400 feet to the summit of Jacks Mountain.

At Mapleton (m.163) the river turns abruptly eastward and flows through a spectacular notch in Jacks Mountain. East of the mountain

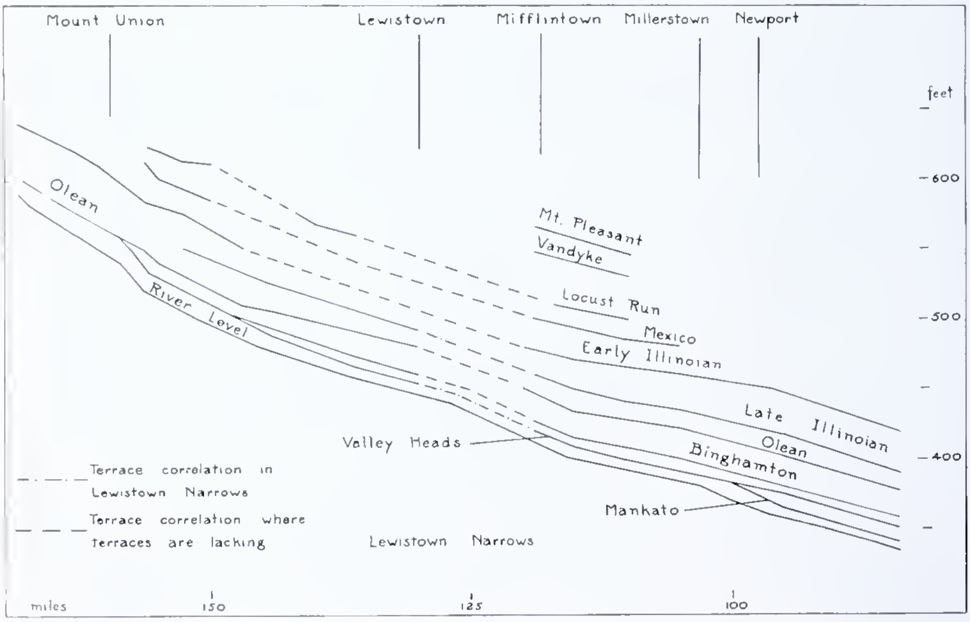

FIGURE 43. Profile of grades of the several terrace systems on the Juniata River.

the enclosed meanders increase in amplitude in the belt of limestone and shale of this part of the valley. These rocks form hills which rise to two general levels: the lower to about 170 feet above the river, and the upper to about 310 feet. Above these relatively low hills rise the mountains, the smaller and narrower of which stand about 600 feet above the river. The larger mountains stand 1500 to 1700 feet above the river. Three miles below Mt. Union (m.160) there is a break in the gradient of the stream (fig. 43, p. 120) accompanied by rapids. At this locality the river is actively eroding its bed at the present time.

Three miles below Mt. Union the river turns sharply toward the northeast. For the next 28 miles it follows the northwest flank of Blue Mountain in a hilly valley cut in limestone and shale. At Newton Hamilton (m.154) there is a rock bench 140 feet above the river. Near Vineyard (m.150) the river passes through a narrows surrounded by steep slopes which rise to hilltops 600 feet above. Below this point (m.147) the valley broadens and low terraces appear. In this broad valley section, which continues to the Lewistown Narrows (m.129), the river follows a meandering course through hills which rise 120 to 360 feet above it. On both sides are mountains, Jacks and Blue Mountains, which rise to 1900 and 2000 feet above sea level.

At Lewistown (m.130) the Juniata turns southward into a gorge cut through Blue Mountain and then flows through a steep-sided, narrow valley between Blue and Shade Mountains. On either side the valley walls rise for about 1600 feet. They are covered with a thick body of rubble, described on page 70, and their surfaces are strewn with large, angular, quartzite boulders. Wherever the interstitial soil has been washed from around the surface boulders, trees and brush are absent. Barren, talus-like boulder surfaces are characteristic of the slopes and are plainly visible from the highway. There is a distinct steepening of the stream grade in this narrow canyon which begins at an elevation of 440 feet above sea level at mile 127, as shown in Figure 43 (p. 120). The accelerated gradient extends for 12 miles from this point. At Macedonia (m.123) the river flows around the eastern end of Blue Mountain and across another hilly valley, 9 miles wide, which lies between Shade and Tuscarora Mountains. The higher hills in this valley rise 400 to 500 feet above the river and extend as long, narrow ridges parallel to the adjacent mountains. Below them are lesser hills, of shale, chert and limestone, which rise 150 to 250 feet. At Tuscarora (m.113) the river turns and flows eastward, for 9 miles, along the base of Tuscarora Mountain. Throughout this distance the left bank rises rapidly to a height of 110 to 140 feet. At this level there is a gently undulating plain, 4000 feet wide, cut on limestone and containing shallow sink holes. This surface was described by Leverett (1934) and considered by him to be the Illinoian terrace. As shown on pages 128 to 130, this plain, which was formed in pre-Illinoian time, contains deposits of both Illinoian and pre-Illinoian gravel.

One mile north of Millerstown (m.103) the river turns southward, cuts through the eastern end of Tuscarora Mountain, and flows southward in a narrow valley to Newport (m.98). Except where it passes the junction of Buffalo and Berry Mountains, the river is flanked by hills which rise about 200 feet. Two miles below Millerstown at 379 feet above sea level the grade of the river steepens, forming the lowest nickpoint on the Juniata. The stream flows eastward from Newport for 6 miles, then southward for 5 miles to its junction with the Susquehanna. The valley in this section is like that below Millerstown, save for the development of alluvial deposits at the meanders.

TERRACES

General Statement.

The Juniata River is the largest tributary of the Susquehanna River whose drainage basin appears to be entirely outside of the glaciated region. No pebbles foreign to its drainage basin have been found by the writer on the gravel terraces of the Juniata. These gravel terraces cannot, therefore, be considered glacial outwash, and yet they correspond in number, relative height and in degree of weathering, to those along the Susquehanna River (fig. 43, p. 120 and Table 46, p. 122). It is obvious that the Juniata terraces have developed contemporaneously with those of the Susquehanna, but the grade of the Juniata is too steep for one to suppose that changes in grade of the Susquehanna caused deposition and erosion on the Juniata.

Except in the neighborhood of nickpoints in the stream gradient, the terraces of the Juniata decrease, in height above the river, upstream. Of the Wisconsin terraces, only the Olean terraces extend as far upstream as Mt. Union (m.160); the other Wisconsin terraces successively decrease in height upstream and become buried by younger deposits.

All of these terraces are composed of a thin deposit of gravel lying upon a rock bench. These gravels were previously studied by Bashore (1896), Leverett (1934) and Campbell (unpublished data in files of Penn. Geol. Surv.). Bashore found that high gravel deposits existed on the valley walls near Losh's Run (m.87) up to a height of 130 feet above the river, or 30 feet above the level which Leverett reported for his Illinoian terrace in the same locality. Bashore reported granite pebbles in these high-level gravels, but this observation has not been verified. The unpublished observations made in the Juniata Valley, between Mt. Union (m.160) and Newport (m.98), by M. R. Campbell, were available to the writer. Campbell found gravel deposits, up to 200 feet above the river, throughout this distance. Leverett found pebbly deposits 400 feet above the river near Huntingdon. These deposits must be at least as old as the highest gravel found by Campbell, and the writer agrees that Leverett's attribution of a pre-Pleistocene age seems reasonable.

At present the relative age of the gravels and the rock benches on which they lie is debatable. The rock benches may have been cut contemporaneously with deposition or may be older. If older they may have been cut during the interstadial period immediately preceding the alluviation, or they may, in each instance, be considerably older. The rock surfaces below the gravels are as fresh as the gravels. The gravels were brought to place by strong currents. For these reasons one must suppose that the benches were recut by the river

[illegible]	McKees[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	[illegible]			55	
			[illegible]	45		
[illegible]	McKeesport	[illegible]	[illegible]	20	[illegible]	[illegible] pebbles [illegible] 3 ft and 23 ft wide
[illegible]	McKeesport	right	[illegible]	10	35	Clayey silt
			[illegible]	25		
[illegible]	Wakefield Run	left	[illegible]			
			[illegible]	45		
			[illegible]	[illegible]		
[illegible]	[illegible]	right	[illegible]	[illegible]		Re[illegible] gravel on rock bench
[illegible]	Anderson	right	Mt. Pleasant(?)	158		Cobbles on rock bench
[illegible]	Anderson	right	[illegible]	45		
			[illegible]	85		
			Mt. Pleasant(?)	170		Weathered pebbles on outcrop of [illegible] shale
[illegible]	[illegible]	left	[illegible]	91		3.5 ft of buff clayey, pebbly silt with brick-red stains lying upon rock bench
[illegible]	[illegible]	right	Valley Heads	0		
			[illegible]	11		4 ft of gray to buff pebbly silt exposed
			[illegible]	35		
			[illegible]	40		
			[illegible]	[illegible]		
			[illegible]	100	[illegible]	Surface strewn with angular and subangular sandstone pebbles and cobbles. This is probably an alluvial fan deposit of Minehart Run.
[illegible]	[illegible] Mills	left	[illegible]	33		Silt
[illegible]	[illegible]	left	[illegible]	34		
			[illegible]	[illegible]		
[illegible]	Mt. Pleasant	left	[illegible]	45		
			[illegible]	[illegible]		
			Mt. Pleasant	112		[illegible] inches of gray, leached silt, pebble loam underlain by compact, red, clayey, pebbly loam
[illegible]	Port Royal	right	[illegible]	[illegible]		
			[illegible]	[illegible]		
			[illegible]	[illegible]		
			[illegible]	85		
[illegible]	[illegible]	[illegible]	Valley Heads	6	50	
			[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	150	
[illegible]	[illegible]	left	[illegible]	[illegible]	240	[illegible] ft of sand containing pebbles and cobbles exposed
			[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	Surface strewn with boulders of sandstone and chert in a matrix of pebbles, small cobbles and fine sand. [illegible] shale, limestone crops out 56 ft above the river and is overlain by reddish-brown pebbly sand.
			[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	Surface covered with clayey, fine sand containing rounded, transported pebbles and boulders of quartzite
			[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	270	Surface strewn with angular and rounded pebbles in a clayey matrix
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
			[illegible]	[illegible]		Rounded pebbles found up to 110 ft. above the river
	[illegible]		[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	Gravel
			[illegible]	[illegible]	[illegible]	[illegible] Surface strewn with rounded and subangular pebbles
		left	[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	[illegible] gravel lying upon rock bench

[illegible] are estimated

penecontemporaneously with deposition, but this brief episode may not have been an effective agent in producing the bench. It may have merely removed the weathered rock from a bench previously formed either by weathering at the base of a higher slope or by lateral planation at a time of still-stand in the lowering of the valley.

Nine levels of gravel deposition occur in the valley, (fig. 43, p. 120 and Table 46, p. 122). The Mankato terraces were observed only near the junction with the Susquehanna River and probably do not extend above Newport (m.98). The Valley Heads terraces are low terraces, about 7 feet above the river. Like those along the upper part of the West Branch, described on page 105, they are probably composite terraces and contain deposits which range in age from Valley Heads to Recent. Binghamton terraces were not recognized above the nickpoint in the river (m.156) near Mt. Union. Downstream they occur at an average height of 15 feet. The Olean terraces lie about 28 feet above the river. These terraces were identified on the basis of weathering and relative height with respect to the lowest Illinoian terrace.

The Illinoian terraces are easily recognized by their weathering. They lie on two gradients: a lower or Late Illinoian grade which is about 52 feet above the river, and an upper grade of Early Illinoian age, which is about 75 feet above the river. These grade lines are distinctly below the level of the terraces which Leverett (1934) identified as Illinoian, and it appears that he identified as Illinoian all of the gravels which are here considered to be of pre-Illinoian, but Pleistocene age.

Deposits of gravel containing rounded and transported pebbles, which obviously must be interpreted as stream gravels, occur at various elevations above the Illinoian deposits. They form terrace systems which are in part fragmentary (fig. 41, p. 115). The average heights at which these terraces occur are: Mexico terrace, 88 feet; Locust Run terrace, 108 feet; Vandyke terrace, 135 feet; and Mount Pleasant terrace, 160 feet. Other deposits of gravel, which have not been related to a terrace system, occur about 200 feet above the river. These gravels, previously described by Leverett (1934), are almost certainly Tertiary in age. The gravel at 135 feet appears to be related to the granite-bearing gravel which Wright (1892) and Bashore (1896) described from the Paxton terrace at Harrisburg. It is, therefore, probably Early Pleistocene in age.

With the exception of the Mexico terraces, the remnants of these higher deposits are poorly preserved and few in number. The reconstruction of their grade lines, here presented, must be considered tentative and subject to revision. They do, however, demonstrate that there were other pre-Illinoian stages of alluviation along this river during the Early Pleistocene.

Mankato Terraces.

Throughout most of the Juniata Valley the deposits of Mankato age apparently lie on the same terraces which contain deposits of both the Valley Heads glacial episode and post-Pleistocene time. However, south of Millerstown (m.103) the Mankato and younger deposits lie at a distinctly lower level. No deposits definitely identified as Mankato in age have been found in this valley.

Valley Heads Terraces.

Terraces, whose relationship to the older terraces indicates that they may be, in part, of Valley Heads age, occur along the Juniata River below McVeytown (m.142). These terraces vary from 5 to 10 feet in height and are usually covered with slightly weathered, buff- to tan-colored, fine-grained sand, silt or clayey silt. Wherever the gradient of the stream is steep, as it is near Tuscarora (m.113), these fine-grained sediments are absent and the bed and banks of the river are composed of rocks from an inch to a foot in diameter. Gravel may be actively transported along these steep parts of the stream, but its absence along the more gently graded parts of the river indicates that no gravel is being carried here. At the time that gravel was transported along the entire course of the river to form this terrace, there must have been a different regime of the stream from that which now prevails. The stream must have had higher velocities to carry the gravel load.

Because no terraces lie below the Valley Heads terraces, they may be composite in nature and contain the gravels of the Valley Heads and Mankato sub-stages as well as the overbank deposits of inter-stadial and Recent times.

Binghamton Terraces.

Terraces thought to be of Binghamton age occur along the river below the nickpoint (m.156) near Mt. Union. This nickpoint is reflected in the grade lines of all of the terraces up to the Early Illinoian, as shown in Figure 43, (p. 120), and it is apparent that the nickpoint did not migrate upstream by a significant amount after Early Illinoian time. In many instances the terraces are covered with buff-colored silt in which there are rounded pebbles. As is shown in Table 46, (p. 122), the Binghamton terraces occur from 14 to 20 feet above the river. This height is everywhere below the level of the flood of March, 1936. Obviously the silt blanket must be, at least in part, a deposit of the overbank flow of modern floods.

Olean Terraces.

The terraces of Olean age were traced from Mt. Union (m.160) to the narrows (m.106) near Thompsontown. Throughout most of this distance these terraces lie at or below the level of the 1936 flood, and their surface is commonly strewn with cobbles in a matrix of tan-colored silt.

At McVeytown (m.144) the Olean terrace, shown in Figure 43, (p. 120) and Table 46, (p. 122), is 28 feet above river level. At the edge of this terrace there is, exposed in a road cut, a deposit of red, compact, clayey silt at least 2 feet thick. Rounded to sub-angular pebbles and cobbles of red and gray sandstone are scattered throughout the deposit. This material appears to have undergone the same amount of weathering that has altered the Illinoian glacial deposits, described on page 43, and was probably deposited during Illinoian time. One may, then, conclude that an Illinoian deposit was, during Olean time, eroded and cut down to the Olean grade line. The occurrence of Illinoian sediments only 26 feet above the present river level indicates that the Juniata River at this place, like the Susquehanna River at Selinsgrove (p. 113), has lowered its channel only slightly since Illinoian time.

Late Illinoian Terraces.

The eroded remnants of a body of gravel which once completely filled the Juniata Valley, occur, from place to place, at heights of from 48 to 62 feet above the river, as is shown in Table 46 (p. 122). This gravel train must have been graded at a later time than was the similar gravel which lies above it and, by analogy with the Wisconsin terraces, it is supposed that it represents the deposits of a separate glacial sub-stage within Illinoian time.

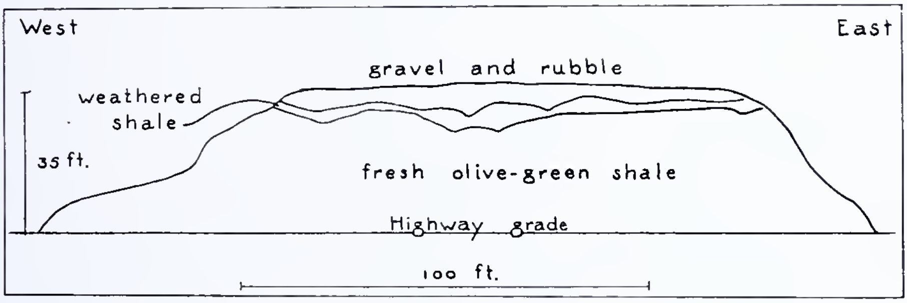

Figure 44. Geologic section of rock bench on U. S. Highway 22 near Mt. Union (m.161).

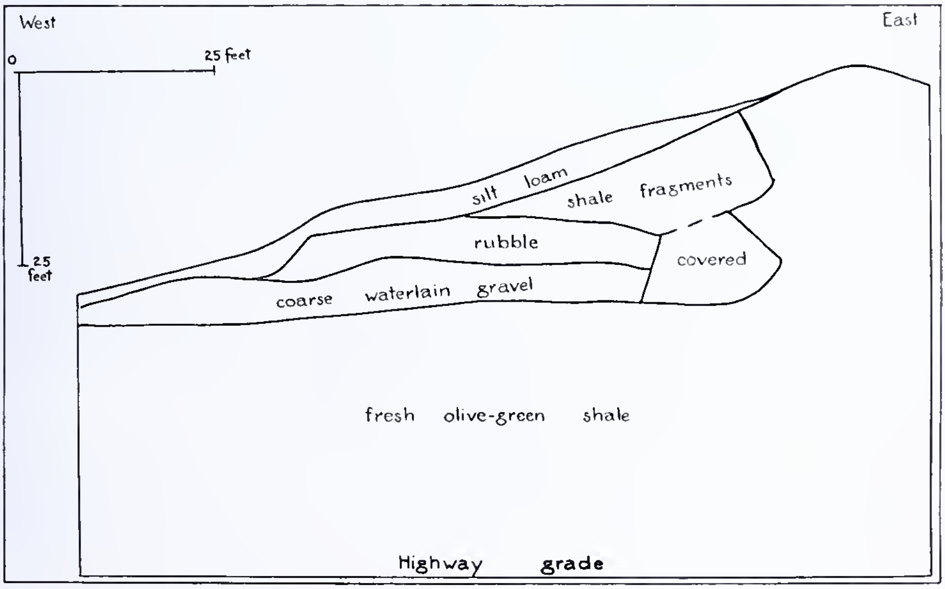

Figure 45. Geologic section of rock bench on U. S. Highway 22 near Mt. Union.

Deposits which are correlated with this sub-stage occur opposite Mt. Union (m.160), 58 feet above the river. Here, remnants of a rock bench cut in Rose Hill, olive-green shale, shown in Figures 44 and 45, (p. 125), are covered by a bed of rusty, boulder gravel, 2 to 5 feet thick, composed of large, angular boulders 3 feet in diameter, in company with rounded and angular cobblestones and boulders, in a light-brown,.clayey silt matrix (Table 46, p. 122). In a few places the original imbrication of the rounded pebbles is present as a proof that this is an alluvial deposit and not a congeliturbate like the overlying deposit of coarse, angular fragments shown in Figure 43 (p. 120). At the surface there is a thin, 6-inch deposit of compact, clayey silt containing scattered pebbles, overlain by 6 to 8 inches of loose, buff- to tan-colored, pebbly silt loam. These deposits are interpreted as the products of two glacial stages. During Late Illinoian time the fluviatile gravel was deposited and was later disturbed as a congeliturbate moved over it. During the post-Illinoian interval these deposits were weathered and the underlying rock was weathered and stained a brick-red color to a depth of 3 feet. The thin deposits of silt were probably laid down as loess during Wisconsin time.

Early Illinoian Terraces.

The Early Illinoian sub-stage is postulated on the basis of gravel deposits which are known at only six localities (Table 46, p. 122). The gravels at these places have distinctive Illinoian weathering, but they lie as terrace remnants about 23 feet above the gradient of the Late Illinoian terraces and on a grade line between 65 and 83 feet above the river (fig. 43, p. 120). A more thorough search of the valley would presumably yield additional remnants of this terrace system.

At the river bend 4 miles below Mt. Union (m.160) there is a distinct break in the slope at a height of 77 feet, or about 15 feet above the Late Illinoian terrace. Above this the slope is, for 300 feet, a gentle one and the surface is strewn with boulders and cobbles up to 3 feet in diameter embedded in a red, clayey matrix. Three miles further downstream, opposite Newton Hamilton, there is a corresponding bench, 100 feet wide, which rises 20 feet above the Late Illinoian bench to a height of 72 feet. Other remnants of this system occur near Mifflintown and are described on page 128.

Pre-Illinoian Terraces.

Terrace remnants and gravel patches occur at various elevations (Table 46, p. 122), above the oldest and highest Illinoian gradient. They lie as high as 175 feet above the river and the gravel appears to be more deeply weathered than the gravels attributed to Illinoian time. Presumably these remnants represent three or more older gradients of the river. The available data with respect to these terraces is, however, limited, and conclusions with the respect to the number of river gradients represented or the ages that might be assigned cannot now be definitely ascertained. Most of these terrace systems occur near Mifflintown and are discussed in detail on pages 129 to 130.

Rock Benches.

The pre-Wisconsin gravel deposits along the Juniata River commonly occur as a thin veneer lying upon a rock bench. In most instances this veneer is so thin that the elevation of the rock bench is essentially that of the overlying gravel terrace. One cannot suppose (p. 122) that these particular benches were cut *pari passu* with the deposition of the gravel. These rock benches must have existed before Late Illinoian time. By analogy it is presumed that similar relationships exist between the older gravels and the higher rock benches.

The rock benches owe their present elevation to the migration of successive nickpoints from the mouth of the Susquehanna River toward the headwaters of that stream and all of its tributaries, as is shown by the experiments of Lewis (1944, 1945). These migratory nickpoints, as distinguished from breaks in the stream grade caused by a confluence of streams or lithologic discontinuity in the stream bed, must owe their origin to changes in stream flow and the relative position of the land with respect to sea level. All of the migratory nickpoints on the Juniata River must be older than Late Illinoian, for the Late Illinoian gravel terrace is adjusted to some nickpoint, further downstream below the mouth of the Juniata. It is, therefore, likely that the gravel deposits are distinctly different in age and younger than the rock benches on which they lie.

SELECTED LOCALITY

Mifflintown.

The most complete flight of terraces along the Juniata River occurs between Mifflintown (m.119) and Thompsontown (m.108) (fig. 46, p. 128 and Table 46, p. 122). Here gravel-strewn terraces at eight different elevations occur in such close proximity that they must represent eight different periods of alluviation.

The youngest terraces are those which lie 6 or 8 feet above the river. They are narrow terraces and rarely exceed 50 feet in width. They are composed, at the surface, of the same kind of material which covers the adjacent river bed. In some instances this is a brown, sandy silt containing scattered pebbles, and in other instances a shingle composed of ellipsoidal to sub-angular pebbles and cobbles from an inch to a foot in diameter. Two terrace systems lie between these terraces and the lowest terraces that are composed of red, weathered gravel of Illinoian age. It is, therefore, supposed that the 6- to 8-foot terraces can be no older than Valley Heads in age. Because there are no lower terraces, they probably contain deposits which range in age from Valley Heads to Recent.

The Binghamton terraces lie from 11 to 18 feet above the river. They occur at nearly every point along the river and their width, which ranges up to 800 feet, is commonly greater than that of the younger terraces. Their materials are similar to those of the younger terraces. The river bank and a shallow pit near the river exposed medium- to coarse-grained sand containing pebbles and small cobbles. Four miles further downstream, near Locust Run (m.110), the pebbles predominate and the terrace is composed of medium- to fine-grained gravel in a sandy matrix. These terraces are commonly covered by modern floodwaters and, in some places, as near Port Royal (m.116), they are covered with at least 2 feet of buff-colored silt.

The Olean terraces lie between 32 and 36 feet above the river. They are usually about 4000 feet long and 300 feet wide and are separated

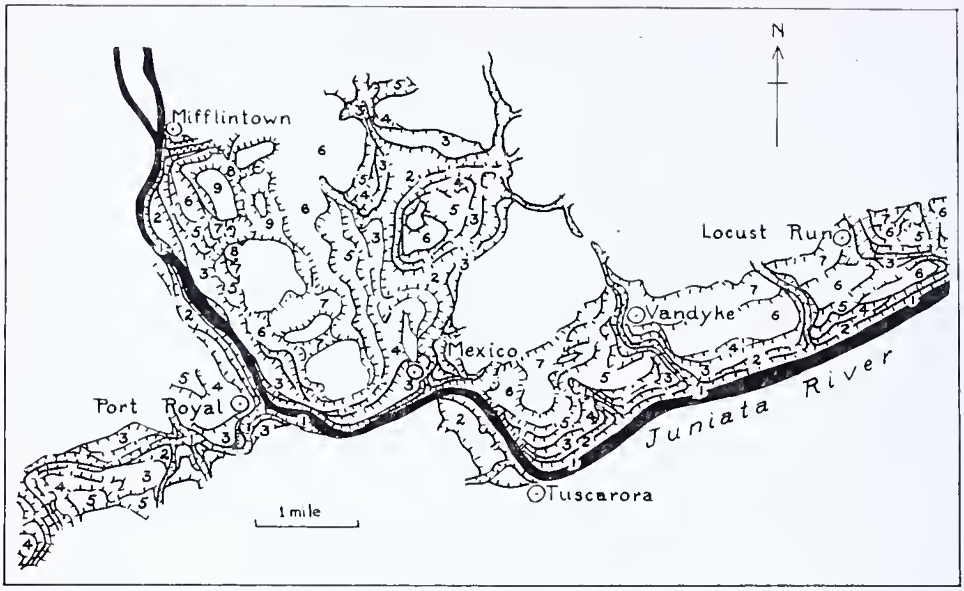

Figure 46. Map of Juniata River near Mifflintown showing distribution of terraces.

LEGEND

Terrace Number	*Terrace*
1.	Valley Heads to Recent Composite Terrace
2.	Binghamton Terrace
3.	Olean Terrace
4.	Late Illinoian Terrace
5.	Early Illinoian Terrace
6.	Mexico Terrace
7.	Locust Run Terrace
8.	Vandyke Terrace
9.	Mount Pleasant Terrace

from each other at places where the valleys of tributary creeks are cut below the terrace level or where the lateral erosion of the post-Olean floods extended to the valley walls. The level of the flood of March 1936 was close to the level of the Olean terraces along this part of the river, and it is likely that on rare occasions parts of these terraces are covered by modern floods.

The Late Illinoian terraces lie about 50 feet above the river and occur as remnants about 4000 feet long and 300 feet wide. The surface of the Late Illinoian terrace near Vandyke (m.112) is covered with cobbles of red sandstone, gray sandstone and chert in a weathered matrix of pebbles and fine-grained sand. This terrace is 340 feet wide and rises gradually from 48 to 56 feet. At the inner edge of the terrace the underlying limestone crops out, showing that the floodwaters of Late Illinoian time abraded and undercut the higher Illinoian terrace.

The remnants of the Early Illinoian terraces are few and poorly preserved. They occur in scattered places along the left bank of the Juniata River between Mifflintown and Thompsontown where they form narrow benches, usually about 100 feet wide, between 69 and 78 feet above the river. At Thompsontown a terrace remnant lies 78 feet above the river and represents the Late Illinoian system. A vertical section in this terrace, previously discussed on page 46, is shown in Table 21 (p. 46). Weathered, reddish-brown, poorly sorted gravel and fine-grained sand, 7 feet thick, lie on a rock bench cut in Bloomsburg shale. A pebble count of this gravel, given in Table 3, p. 18), indicates that, although the pebbles are varied in composition and are derived from formations which range in age from Upper Ordovician to Mississippian, they are composed entirely of rocks which occur within the present drainage basin of the Juniata River. This gravel contains angular fragments of red shale (which made up about ¼ of the pebbles in the sample), apparently derived from the underlying rock bench. After the gravel was deposited, it was probably stirred up by frost in the manner described on page 69. Frost-splitting of the pebbles in the gravel also explains those pebbles (30 per cent of the total) which have some edges sharp and others rounded as though water-worn. Only about 40 per cent of the pebbles in this deposit are completely rounded and retain all of their original, water-worn surfaces. This gravel deposit has, therefore, undergone a considerable amount of change through physical and chemical weathering since it was laid down.

There are, in this locality, four terraces of different ages which lie above the Early Illinoian terrace. Names, derived from small towns near which these terraces occur, are given to them for the purpose of identifying and distinguishing the terraces. These terraces have not been correlated with the high-level terraces in the Susquehanna Valley, although it is likely that the Mexico and Locust Run terraces, described below, may be related to the Highspire and Paxton terraces respectively, page 118.

The Mexico terraces are the most frequently encountered of the high-level terraces along the Juniata River. This terrace system is named from a type locality, the terrace on the left bank of the Juniata River 1½ miles east-southeast of Mexico (m.115). Here the terrace is 300 feet wide and has an outer edge 87 feet above the river, or 484 feet above sea level, and an inner edge 98 feet above the river. The surface is covered with reddish-brown sand containing sub-angular and rounded cobbles and pebbles. The underlying gray limestone bed-rock appears to be near the surface nearly everywhere so that this terrace is essentially a rock bench with a thin gravel veneer. Terraces at similar elevations occur along the left bank of the river between Mifflintown and Thompsontown, and along Cedar Spring Run north of Mexico.

The Locust Run terraces are named from a locality 3000 feet south-southeast of Locust Run (m.110) where there is a terrace at an elevation of 108 feet above the river, or 500 feet above sea level. The surface of this terrace has about 7 feet of relief and it is strewn with sub-angular to rounded, transported pebbles.

The Locust Run terraces are particularly well developed between Mexico and Thompsontown. This locality was described by Leverett (1934), who considered the gravel to be of Illinoian age. Indeed the gravel of this terrace cannot be readily distinguished from that which occurs on the lower-lying Illinoian terraces. Its surface, though undulating and containing some "undrained" depressions due to solution of the limestone, is strewn with pebbles and is easily recognized as a somewhat weathered, gravel-covered rock bench. Leverett (1934) considered that the depressions were due to irregularities in the deposition of the gravel. It may be that initial irregularities and scour depressions occurred in the river gravel. If such original depressions existed, they probably influenced the location and orientation of the present depressions. However, it is unlikely that a depression near the crest of the bench, such as occurs at mile 111, would now contain standing water if it were surrounded only by gravel. Furthermore, the relief on this terrace appears to exceed the thickness of the gravel deposits and should be attributed to solution of the limestone subsequent to deposition of the gravel.

The Vandyke terraces are named from a locality 1½ miles southwest of Vandyke where there is a terrace about 200 feet wide and 139 feet above the river, or 537 feet above sea level. The surface has a relief of about 10 feet and is covered with a clayey silt containing both angular and rounded pebbles of sandstone and chert. The riverward-facing foreslope of this terrace, 5 to 10 feet high, was described by Leverett (1934) as a river bluff. Other terraces of the same age occur at about the same height on the left bank opposite Port Royal (m.116) and on the north side of Vandyke (m.112), where rounded pebbles were found up to 140 feet above the river.

The Mount Pleasant terraces are named from a locality 3800 feet northwest of Mount Pleasant (m.117) where there is a terrace about 500 feet wide and 155 feet above the river, or 565 feet above sea level. Its surface (p. 46) is covered with deeply weathered silt loam that contains angular and rounded pebbles of chert, pink quartzite and sandstone. Another terrace of the same characteristics and altitude occurs 1½ miles southwest of Vandyke immediately above the type localities of the Mexico and Vandyke terrace systems. This terrace is 155 feet above the river and about 50 feet wide. Its surface is covered with both angular and rounded pebbles which (Table 3, p. 18) are derived from several different formations. The deposit consists of materials obviously stream-transported.

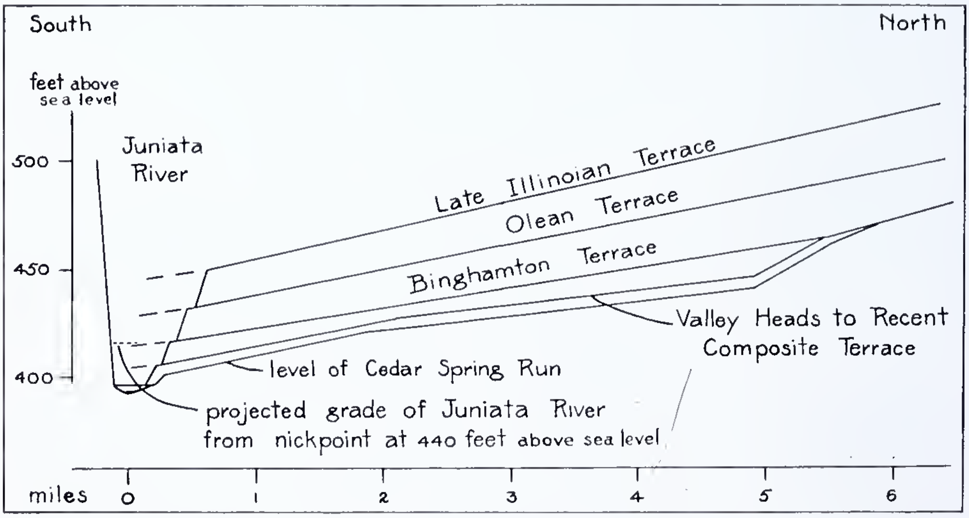
South
North
feet above sea level
500
450
400
Juniata River
Late Illinoian Terrace
Olean Terrace
Binghamton Terrace
Valley Heads to Recent Composite Terrace
level of Cedar Spring Run
projected grade of Juniata River from nickpoint at 440 feet above sea level
miles
0
1
2
3
4
5
6

Figure 47. Profile of grade lines of the several terrace systems on Cedar Spring Run (m.115).

On the streams which flow into the Juniata River near Mifflintown, the profiles of the Late Pleistocene terraces show that terrace grade lines originate at nickpoints in the stream bed. Further there is a direct relationship between the distance from the mouth of the stream to the nickpoint and the time since the nickpoint was first formed at the mouth of the stream. In general, therefore, the terraces decrease in height toward the headwaters of the tributary, but this decrease is not continuous and gradual. Sudden changes in the height of the terraces occur in the neighborhood of the nickpoints.

The relationship of the terraces to the stream gradient along Cedar Spring Run (m.115) is shown in Figure 47 (p. 130). The nickpoint in the stream grade 5½ miles above the mouth (fig. 43, p. 120) appears to represent the erosion below the Binghamton terraces and probably began, at the mouth of the creek, after the Binghamton sub-stage. If the gradient above the nickpoint on the Juniata River at 440 feet above sea level at mile 127, described on page 121, is extended to the mouth of Cedar Spring Run at mile 115, the elevation of this projected grade line coincides with the elevation of the Binghamton terrace (fig. 43, p. 120). Presumably, then, the nickpoint at 440 feet above sea level on the Juniata River and the nickpoint at 460 feet above sea level on Cedar Spring Run are of the same age, and, as there is no break in the slope of the Binghamton terrace, between the mouth of Cedar Spring Run and either the 440-foot or 460-foot nickpoint, such as one might expect to find where the gravel train crossed a nickpoint, it may be concluded that the 440-foot nickpoint on the Juniata River retreated past the mouth of Cedar Spring Run at some time after the Binghamton sub-stage. Similar consideration of the tributary creeks near Thompsontown (m.108) and Millerstown (m.103) indicates that the 440-foot nickpoint probably retreated about 23 miles in post-Binghamton time.

The deposits of modern floods on Cedar Spring Run appear to bear essentially constant relationship to the stream gradient (fig. 47, p. 130). They, therefore, overlie the Binghamton terrace near the headwaters and overlie the Valley Heads terrace near the mouth. Similar relationships with older terraces may have existed along the creek in the past, and these terraces may contain flood-deposited silts which are distinctly younger than the gravel deposits.

Pleistocene Climate of Central Pennsylvania

GENERAL STATEMENT

When ice covered the upper part of the Susquehanna Valley and all of the land to the north, the effect of the ice surface upon the climate of the adjacent region must have been great and the climate of Pennsylvania quite different (fig. 48, p. 133) from that of the present (fig. 49, p. 134). The fact that so large a body of ice remained for a long time implies a difference in the general meteorological conditions from those of today. Under present conditions there is a poleward transfer of heat which brings about a balance in the energy distribution and maintains a constant temperature difference between the equatorial and polar regions (Haurwitz, 1941). The advance or retreat of a polar ice cap depends upon a delicate balance of climatic conditions. If the quantity of precipitation which falls as snow or is frozen into ice exceeds the quantity lost by melting and evaporation or blown away, the ice cap will grow. If these relationships are reversed it will disappear. The alternation of the climatic events of glaciation and deglaciation has been explained either by varying the losses due to melting (Penck and Brückner, 1909), by varying the rate of precipitation (Simpson, 1934), or both.

The observations of Meyer (1904), Klute (1928, 1937), Nilsson (1935) and others have shown that, in the past, there was not only greater glaciation and a lower snow line on the mountains at high latitudes, but also on the mountains of the equatorial regions. If one supposes that the cold periods of the tropics alternated with those of high latitudes, the present glaciation in the tropics should now be near its maximum extent and there should be a line of no depression of the snow line and no variation in the size of mountain glaciers which would be roughly parallel to the equator and located in the mid-latitudes. No such line has been recognized, and the retreat of mountain glaciers in the tropics is comparable in amount to that in other latitudes. Therefore the conclusions of Köppen and Wegener (1924), that during a glacial stage there was a higher snow line and less glaciation in the tropics than now, are contrary to fact.

Whatever the causes which led to glaciation, the existence of a large body of ice over the continent must have had a considerable influence upon the local air circulation. During the winter season the southward extension of tongues of cold air would have been facilitated. A cold air mass probably predominated over the ice sheet, and northward advances of sub-tropical air were rare. During the summer these conditions would have continued. The center of high pressure set up by the radiational cooling by the ice would tend to deflect storms, and extensive invasions of sub-tropical air onto the continent may have been less frequent. The climate of eastern United States, not only where covered by ice, but for at least 500 miles south of the ice edge, must have been distinctly different from that of today.

Some indications of the nature of this climatic change are given by the occurrence of plants, usually considered to belong with a northern flora, as fossils in the Pleistocene deposits of southern United States. Identifiable remains of larch (Larix laricina), white spruce (Picea glauca), and northern white cedar (Thuja occidentalis) are reported from the Pleistocene of Louisiana by Brown (1938). Today, none of these species range south of northern Indiana and Illinois except in the Appalachian Mountains. Berry (1907) also mentions the occurrence of larch in the Pleistocene deposits of Georgia.

Throughout eastern United States there are plants which are more closely related to a flora of higher latitudes than those in which they are found and have a considerable gap in their range. They are found in the higher mountains and cool, dark ravines. It is supposed (Branner, 1887; Brown, 1938) that they were originally confined to the higher latitudes and migrated southward during a glacial stage. When the ice edge retreated these species migrated northward while their parents, in the lowlands, died out. Remnants of this migration appear in favorable places. Brown (1938) considers the staghorn sumac

(Rhus typhina), mountain magnolia (Magnolia Fraseri) and swamp white oak (Quercus bicolor) in Louisiana to be such remnants. Similarly, Berry (1907) considers the Canadian hemlock (Tsuga canadensis) and black birch (Betula lenta), found in an isolated locality in Alabama south of their usual range, to be remnants of an earlier flora.

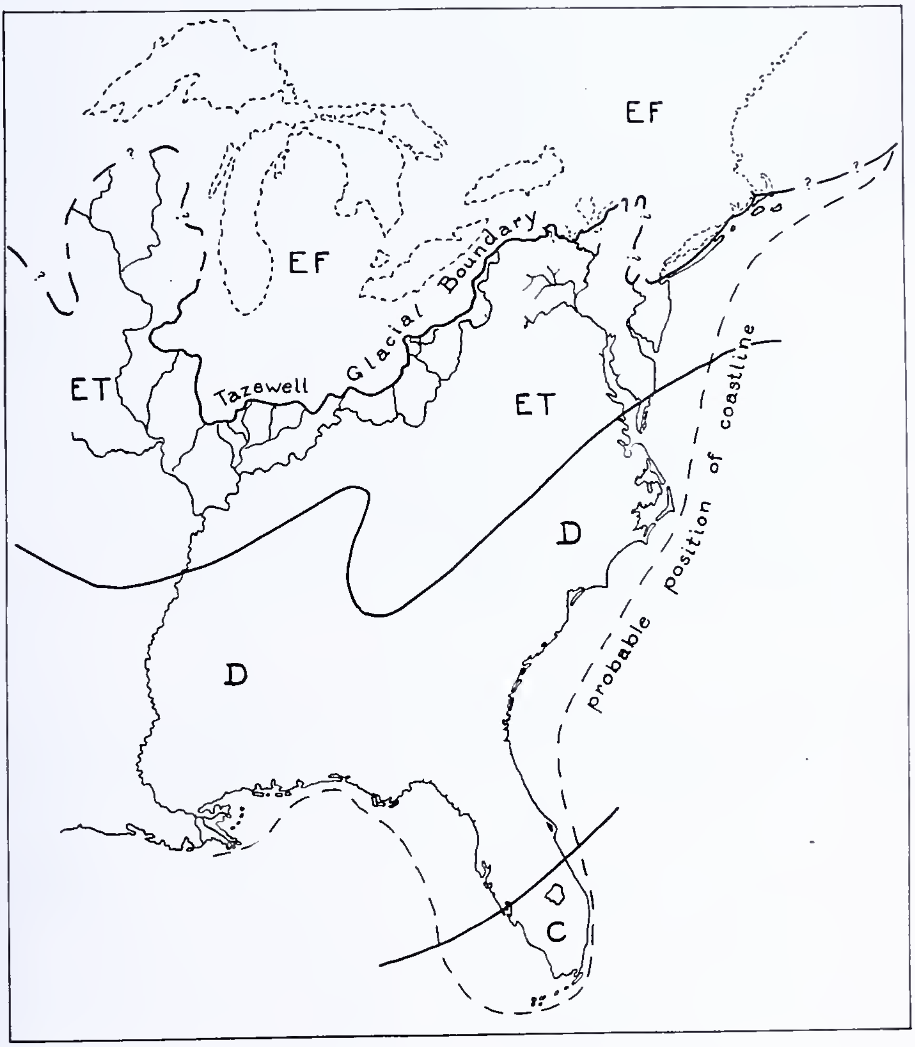

FIGURE 48. Hypothetical map, according to the Köppen system of climatic zones in eastern United States during the Tazewell (Binghamton) glacial maximum.

Statistical studies of pollen in the Pleistocene peat and lake sediments of the South also show the presence of a flora presumed to be northern and alien to the present climate. Buell (1946) found fir and pine pollen common in the clays of Jerome Bog in North Carolina; Cain (1944) found spruce, fir, jack pine (Pinus banksiana) and hemlock pollen in a buried soil in Spartanburg County, South Carolina; Davis (1946) found pollen of spruce and fir in the peats of Florida; and Potzger and Tharp (1943, 1947) found spruce and fir in Lee County, Texas. At each place these fossils are considered to indicate a cooler climate than now prevails and one must conclude that all of eastern United States was cooler at some time in the Pleistocene than at present.

CLIMATE OF A GLACIAL MAXIMUM

Pressure Fields.

During a maximum stage of glaciation the weather was determined by the distribution of air pressure, the properties of the air and the intensity of circulation. Two centers of high pressure were then, as today, of predominant influence over eastern United States: one located over central United States and Canada and the other over the mid-Atlantic Ocean (Azores high) (Starr, 1944). They were probably different in strength, however, the Canadian high which lay over the ice surface being abnormally strong and the Azores high

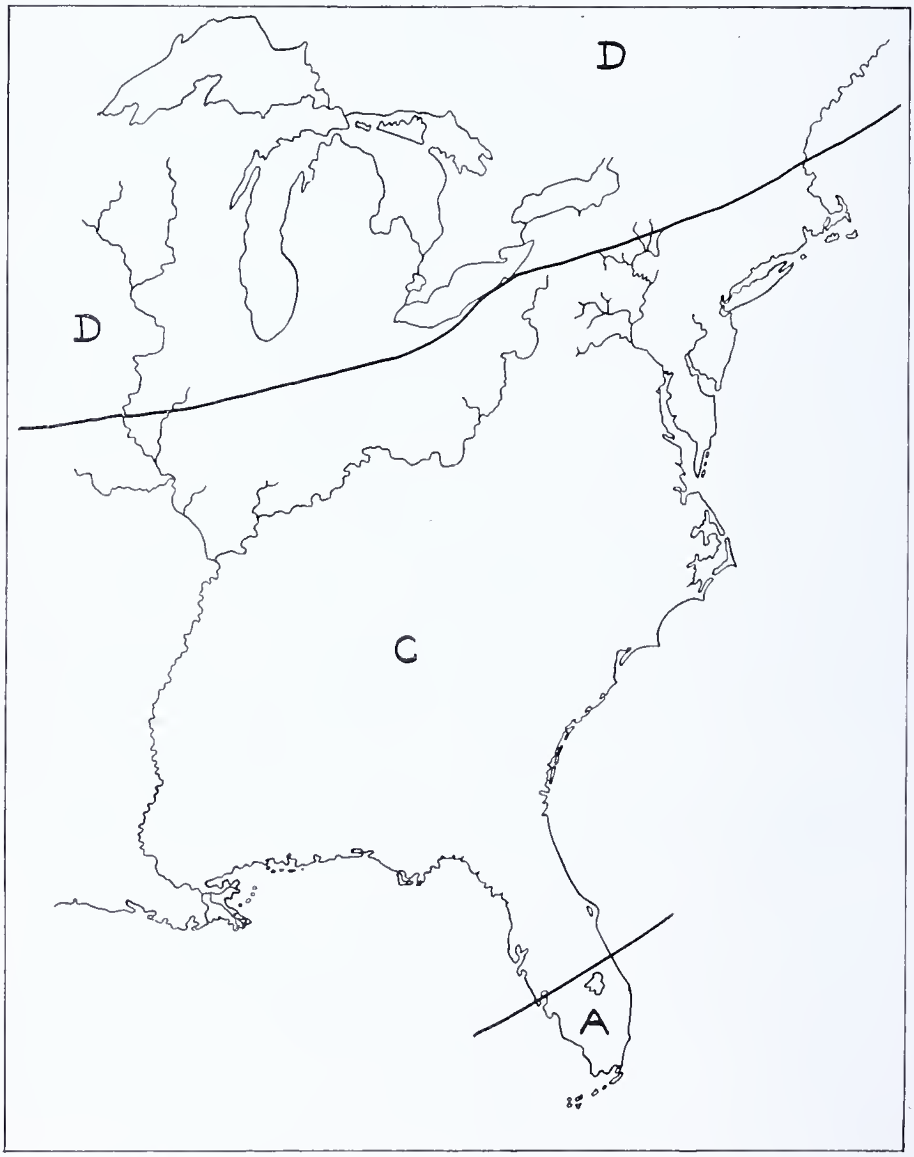

FIGURE 49. Map, according to the Köppen system, of climatic zones in eastern United States at the present time.

relatively weak. The storm paths were probably controlled by two zones of low pressure. One, the Atlantic front, owed its location to the relatively high surface temperatures of the water compared to the adjacent land mass. This was accentuated by the presence of a relatively warm current of water, the Gulf Stream, from the south. This current is the result of the deflection, by the American continents, of a westward moving, equatorial inertia current (Sverdrup, 1942) and its strength should not have been influenced by glaciation although its route across the Atlantic may have been farther south. Also, its temperature may have been lower (p. 136). In the other zone the low-pressure center was variable in its position. It was formed by the abrupt temperature gradient between the ice-covered surface and that of the bare ground or water, and represented the zone of convergence between the air from over the ice and the warmer air from the Gulf of Mexico. Its intensity was largely determined by the kinetic energy resulting from the juxtaposition of warm and cold air masses and by the heat liberated upon the condensation of moisture carried by the southern air. When snow covered the periglacial region and the Azores high was weakest, as one may suppose occurred during the winter, this low-pressure zone was probably located on or near the Gulf of Mexico. In summer, when the periglacial region was snow-free and the Azores high relatively strong, this zone probably lay over or along the ice edge and precipitation from the storms which passed along it brought about the growth of the ice cap as a whole. Seasonal melting was produced by air from the Azores and other centers of high pressure which extended, with slight modification, over the continental ice.

Properties of the Air.

The air which moved out from over the continental ice was probably in thermal equilibrium with the ice surface, for the ice covered an area about 3000 miles in diameter. Its properties were probably very similar to those observed over modern ice caps.

This air must have moved eastward and northeastward onto the continent from the North Pacific Ocean. Since low temperatures prevailed over the land, precipitation probably occurred, not only on the Pacific Cordillera, but also at low elevations, and thus the air became thoroughly desiccated before it reached the interior of Canada. Here the lower strata of air, which may have reached 3000 to 10,000 feet in thickness, were cooled by the ice surface and by reflection of the sun's rays and, as snow radiates at the rate of a black body (Haurwitz, 1941; Conrad, 1942), its temperatures, in its lower layers, certainly dropped to –60 degrees F. or lower. As a result of this extreme coldness, the moisture content of the air was very small. Much of the original moisture of the Pacific air was lost as orogenic precipitation during its passage across the mountains, and that of the lower strata further reduced by frost deposits and ice-crystal fog. The air over the southeastern edge of the North American ice sheet probably had a higher moisture content and seasonably higher temperature than the interior due to the inflow of air from the Gulf of Mexico and the Atlantic Ocean.

The air which moved north and northwestward onto the continent from the Atlantic Ocean and the Gulf of Mexico may have been slightly different in its properties from that of the present. There is some paleontological evidence indicating that the waters of the Atlantic were cooler in the past (Richards, 1944; Chapman, 1940). The air in equilibrium with it would then be cooler and would contain less water than does the present Atlantic air.

This air, as well as that from the Pacific Ocean which moved over the continent, would be warm with respect to the underlying surface and therefore tend to be stable. The modifications of its properties, as it moved northward, tended to make it cooler and drier. The cold air which moved off from the ice cap moved over a land surface that was warmer and more humid. It tended to increase in temperature and moisture content and develop unstable stratification.

Winds.

The flow of air on the immediate surface was usually dominated by the gravity descent of air which had been chilled by the ice. Such a flow is usually a shallow phenomenon. It merges inperceptibly with the circulation of passing pressure systems and at times gives way to these more gentle winds (Dorsey, 1947; Hobbs, 1947; Matthes, 1947). These surface winds, which have been observed in Greenland (Hobbs, 1926; Ferguson, 1930; Wegener, 1939) and Antarctica (Meinardus, 1909; Harrison, 1931), probably reached velocities of 60 miles per hour and possibly 150 to 200 miles per hour as observed in Adelie Land and the Rockefeller Mountains (Harrison, 1931). In a barren, periglacial zone such winds are quite capable of shaping ventifacts and moving sand into dunes. The Appalachian Mountains probably broke the force of these winds, for there is no evidence of such strong winds in the Susquehanna Valley. A velocity of 8 to 10 miles an hour would have been enough to move the sand of the dunes now found there.

These winds should not be considered to have been constant either in force or direction, for these elements depended upon the location and intensity of the low-pressure center and probably varied significantly during the passage of a single storm.

During the calm intervals between these storms a katabatic breeze about 100 to 200 feet thick probably moved down the valleys at velocities of at least 5 miles an hour. Under favorable circumstances these velocities may have exceeded 20 miles an hour. These breezes represented the downvalley drainage of cold air from the ice surface due to differences in the density of air over the adjacent regions and probably augmented by the regional pressure distribution as shown by Tollner (1931). These winds carried no sand or dust, but must have been significant agents in lowering the temperature along the valley.

Winter Weather.

It is supposed that the winter season was characterized by the predominance of a high-pressure area over most of the United States and Canada. The mean storm path probably lay between 25 and 30 degrees north latitude. It passed across Louisiana and Georgia, then extended northeastward to the Icelandic low, essentially as shown by Bryan and Cady (1934). The periglacial zone, here defined as the zone between the mean winter storm track and the ice edge, was overlain by cold, dry air whose temperatures were as low as –20 degrees F. The ground, except where protected by snow, must have been frozen and evaporation of ice from the frozen ground must have occurred in the presence of the dry air. During this season the temperature gradient between the ice sheet or adjacent snow-covered continent and the nearby sea was most abrupt and the strongest winds probably occurred at this time. The loose, fine-grained particles which lay in the upper, dry soil layer just beneath the surface were likely to be swept away by these winds to be deposited as dunes or dust falls.

Summer Weather.

During the summer season it is supposed that the continental anticyclone persisted but weakened, and that the maritime air extended more frequently over the periglacial zone to the ice edge and beyond. At this time the days were longer, the insolation was greater than in winter and warm days followed by cool nights, during which cold air from the glacier and snow fields drained into the valleys, prevailed. This was the season of maximum freezing and thawing, and most of the periglacial frost forms probably developed at this time. This frost action may have been greater than that observed today in the arctic regions, for in high latitudes the diurnal variation of insolation is small, but in mid-latitudes it is great. There may, therefore, have been a greater intensity of freeze-and-thaw action in the mid-latitudes during the glacial episodes than may be observed today in the high latitudes.

The mean storm track formed by the convergence of Continental and Atlantic air probably lay along the ice edge. The interaction of these two air masses must have led to the precipitation of much of the moisture carried by the Atlantic air and, where the storm extended over the ice, this precipitation became part of the ice mass. This was probably the major source of the alimentation of the continental glacier. Along the ice edge the precipitation fell either as rain or as snow, but the snow was soon melted. These rains, and the melting of the ice brought about by the invasion of warm air, produced the major floods near the ice front which are now recorded in the outwash terraces of the Susquehanna and other stream valleys which led away from the ice edge.

Climate.

The climatic zones of eastern United States during the maximum advance of a continental glacier were correspondingly changed. North of the ice edge there was, using the Köppen system, an EF climate (fig. 48, p. 133). Peripheral to this there was a tundra zone of ET climate. It probably extended over the Piedmont and Southern Appalachians, as is indicated by the occurrence of block fields in the Blue Ridge area (Smith and Smith, 1945), by striated cobbles in the Potomac, James and Tennessee Valleys (Wentworth, 1928), and by the rubble deposits in South Carolina (Eargle, 1940; Bryan, 1940), and in Missouri. The widespread occurrence of rubble and related deposits in Pennsylvania indicates that this State lay entirely within the tundra zone. The point at which this boundary crosses the Mississippi Valley is obscure. The occurrence of northern species in the Pleistocene deposists of Florida, Alabama, Louisiana and Texas indicates that a microthermal or D climate prevailed over the remainder of eastern United States. An exception to this is southern Florida, whose climate was probably somewhat cooler than at present and might be classified as a C climate.

CLIMATE OF AN INTERGLACIAL INTERVAL

The interglacial climates appear to have been slightly warmer than that of the present. Cypress trees (Taxodium distichum), whose present northern limit lies in southern Delaware and Maryland, have been found as fossils in Philadelphia (Richards, 1932) and Baltimore (Berry, 1933). The red soils developed upon the Illinoian glacial deposits in the Susquehanna Valley are more similar to the red and yellow soils of North Carolina and Virginia than to the brown earths which have developed on the adjacent Wisconsin deposits. This scanty evidence indicates that the climate of Pennsylvania was, during the interglacial periods, similiar to that of Virginia today.

Under such conditions the mean summer storm path probably crossed Ontario, and invasions of sub-tropical air over Hudson Bay were more frequent than at present. The mean winter storm path probably crossed Virginia.

CLIMATE DURING GLACIAL RECESSION

The climate during the glacial recession represents the transition between glacial and interglacial climate. It may similarly represent an increasing number of invasions of Atlantic air over the ice, particularly in summer. This northward advance of sub-tropical air and the poleward retreat of the polar front must have led to rapid melting and thinning of the peripheral zone of the continental ice and, therefore, to its stagnation. The rapid melting led to more frequent and heavy floods, both diurnal floods and occasional flood peaks brought about by heavy rainfall along the ice edge.

The originally warm air mass, as it moved northward from the ice edge, had already been cooled by its passage over the peripheral ice, and the precipitation was not too great to be absorbed by the ice. The ice behind the peripheral zone, therefore, continued to grow and remained active behind the stagnant zone. As the ice edge melted back, the warm air from the south penetrated farther into the ice-covered zone and the limits of active ice also moved back. Eventually the diameter of the ice sheet became so small that it had little effect upon the invading warm air. At this stage of retreat the ice stagnated as a whole. In the beginning of retreat, however, the ice melted in zones. These zones in northeastern Pennsylvania, as indicated by the kame terraces, had widths of 2 to 10 miles.

As the ice edge retreated and the influence of the cold air diminished, the tundra zone shifted northward over the formerly glaciated regions. This shift was paralleled by the northward migration of the forest belts.

SUMMARY

This reconstruction of Pleistocene climate has been based on scanty geologic evidence and meteorological analogy with present conditions. It is designed to give only a general picture of the climate as it is supposed to have been. Coupled with the climate of an ice advance, concerning which there is no available evidence, the climates of maximum glaciation, glacial recession, and interglacial times constitute a climatic "cycle." The till and outwash deposits previously correlated with glacial maxima indicate that there were, in Pennsylvania, during the portion of the Pleistocene for which evidence exists, at least seven, and probably more, separate and distinct cold periods and, therefore, an equal number of climatic "cycles."

Summary and Conclusions

During the Olean glacial sub-stage, and possibly to varying degrees during the other glacial advances, the ice entered the Susquehanna Valley in two separate ice streams (pp. 17 to 18), one from the Grenville Province and the other from the Hudson Valley. Contemporaneous with each of these glacial advances there formed, along the Susquehanna River and all of its tributaries, thick deposits of sand and gravel which, as explained on pages 77 to 78, formed continuous plains. These deposits, as shown on pages 78 to 79 and 124, are composed of coarser material than that now carried by the streams and consist of gravel which was washed into the streams from the deposits of glacial ice or frost-produced rubble. They, therefore, are deposits which reflect the distinctive climatic environment of that time.

The stream channels were washed free of these deposits early in the interglacial or interstadial periods and the remnants of the preceding alluviation were left as terraces along the valley walls. Such terraces occur on all streams within the Susquehanna drainage basin. Near the headwaters of each stream the terraces, such as those described on pages 88 to 89 and shown in Figure 32, (p. 88), increase in height as one goes downstream from the headwaters, and younger terraces split off and fall below older terraces. Downstream from an optimum point, whose location depends upon the hydrologic properties of the particular stream, the terraces gradually decrease in height.

The terraces of frontal kames, described on pages 86 to 87 and 91 to 97, descend downstream from the marginal kame terraces and merge with the valley train of the same glacial sub-stage. The apex of these fan-shaped frontal kames marks the position of the ice boundary at the time the marginal kame terrace was formed. The length of a single system of marginal kame terraces may be assumed to represent the zone of glacial stagnation which existed during the development of those terraces. At a considerable distance from the source of glacial meltwater, material from the rubble deposits on the valley walls becomes predominant over the glacially derived gravels in the outwash terraces and, as was explained on page 79, the outwash terraces gradually become periglacial terraces. The rubble deposits on the valley walls are, as shown on pages 56 to 67, periglacial congeliturbates which are no longer being formed.

The occurrence of frost-disturbed material indicates that a tundra climate prevailed over all of Pennsylvania during several of the glacial maxima. Rubified soils indicate that the Susquehanna Valley was warmer during the post-Illinoian and pre-Wisconsin interglacial interval than it is today and presumably had a climate approximately like that of Virginia. The magnitude of the climatic fluctuations is therefore fixed between the limits of the modern climates of Virginia and southern Greenland.

Each separate cold period or glacial advance produced a separate and distinct system of terrace remnants. Different terraces in a flight, as explained on pages 88 to 89 and 110 to 111, represent different cold periods. These periods were separated from each other by warmer episodes during which weathering occurred. Each terrace represents a sequence of events which includes: scour of the channel, alluviation, and further scour. Four terraces of Wisconsin age, two of Illinoian age and several of pre-Illinoian age are recognized. All are assumed to be Pleistocene terraces. This sequence of events corresponds to the cyclical sequence of climatic events described on pages 131 to 139. One may, therefore, correlate these terraces with the Pleistocene events elsewhere through the medium of the climatic history. Any geologic event in the Susquehanna Valley, whose relationship to the terraces may be determined, may thus be related to the Pleistocene chronology of other regions (Table 1, p. 4).

GLOSSARY

complex soil—Modern soil profile superimposed on the relics of one or more older profiles. polygenetic.

composite soil—Monogenetic or polygenetic. Soil profile extends downward through two or more "parent materials." Each parent material may have preserved all or part of an earlier soil profile.

congelifraction—The process of splitting apart by frost. *congelifract*—The single fragment split off by frost. *congelifractates*—Rubbles composed of congelifracts.

congeliturbation—The process whereby ground is disturbed by frost. *congeliturbate*—Material stirred up and usually moved down slope by freezing and thawing of the mollisol.

cryoplanation—The process of the reduction of the land in which the primary agents are congelifraction and congeliturbation.

eluvial horizon—(or A-horizon) The soil horizon from which, in the process of soil formation, either by chemical or mechanical means, more or less material has been removed.

feretto zone—Heavily iron-stained zone formed during the weathering of glacial drift.

illuvial horizon—(or B-horizon) The soil horizon into which material has been carried chemically or mechanically.

liesegangs rings—Bands of a precipitate with clear spaces between them, often formed when a precipitant is added to a gel (in contrast with the evenly distributed precipitate formed in a water solution).

mollisol—Seasonally thawed ground above the pergelisol.

monogenetic soils—Soils developed in one climatic regime. ("normal soils")

pergelisol—Permanently or perennially frozen ground.

periglacial—Having a position marginal to but beyond the glacier.

polygenetic soils—Soils developed in more than one climatic regime. (The result of more than one cycle of soil development.)

rubification—The process of making a material red during a period of warm, moist climate.

REFERENCES

Anderson, J. G. (1907); *Contributions to the geology of the Falkland Islands.* Wiss. Erg. d. Schwed. Südpolar Expedition, 1901-1903; Bd. 3, L. 2, 38 p., 9 pl., Stockholm.

Ashley, G. H. (1930); *Age of the Appalachian peneplains.* Geol. Soc. Amer. Bull., vol. 41, no. 4, p. 695-700.

——————(1933); *The scenery of Pennsylvania.* Pa. Geol. Surv., 4th Ser., Bull. G-6, 91 p., 90 ill.

——————(1935); *Studies in Appalachian mountain sculpture.* Geol. Soc. Amer. Bull., vol. 46, no. 9, p. 1395-1436.

Barrell, J. (1920); *The Piedmont terraces of the northern Appalachians.* Am. Jour. Sci., 4th Ser., vol. 49, p. 227-258, 327-362, 407-428.

Bascom, F. (1921); *Cycles of erosion in the Piedmont province of Pennsylvania.* Jour. Geol., vol. 29, no. 6, p. 540-559.

Bashore, H. B. (1894); *The Harrisburg terraces (Pa.).* Am. Jour. Sci., 3rd Ser., vol. 47, p. 98-99.

——————(1896); *Notes on glacial gravels in the lower Susquehanna Valley.* Am. Jour. Sci., 4th Ser., vol. 1, p. 281-282.

Berry, C. T. (1934); *A Talbot cypress swamp at Greenbury Point, Maryland.* Torreya, vol. 34, no. 4, p. 85-91.

Berry, E. W. (1907); *Pleistocene plants from Alabama.* Am. Naturalist, vol. 41, no. 491, p. 689-697.

Beskow, G. (1930); *Erdfliessen und strukturboden der Hochgebirge im licht der frosthebung.* Geol. Foren. Forhandl. Stockholm, Bd. 52, H. 4, p. 622-638.

Bonsteel, J. A. and Bass, T. C. (1940); *Erosion and related land use conditions in the Conestoga area, Pennsylvania.* U. S. Dept. Agr., Soil Cons. Serv., Erosion Survey No. 15, 52 p., 16 ill., 78 maps.

Branner, J. C. (1886); *The glaciation of parts of the Wyoming and Lackawanna Valleys.* Am. Phil. Soc. Proc., vol. 23, p. 337-357.

——————(1887); *Glaciation: its relation to the Lackawanna-Wyoming region.* Lackawanna Inst. Hist. Sci., vol. 1, p. 5-18.

Breuil, H. (1934); *The importance of solifluction in the study of the Quaternary deposits of the north of France and neighboring regions.* Rev. de Géog. Phys. et de Géol. Dynamique, vol. 7, p. 269-284.

Brooks, F. A. and Berggren, W. P. (1943); *Analytical interpretation of density-currents of air chilled by nocturnal radiation.* Trans. Am. Geophys. Union, Pt. I, p. 189-204.

Brown, C. A. (1938); *The flora of Pleistocene deposits in the Western Florida Parishes, West Feliciana Parish and East Baton Rouge Parish, Louisiana.* La. Geol. Surv., Bull. No. 12, p. 59-96.

Bryan, K. (1940); *Soils and periglacial phenomena in the Carolinas.* Science, n. s., vol. 91, no. 2370, p. 523-524.

——————(1941); *Geologic antiquity of man in America.* Science, vol. 93, no. 2422, p. 505-514.

——————(1946); *Cryopedology—The study of frozen ground and intensive frost-action with suggestions on nomenclature.* Am. Jour. Sci., 4th Ser., vol. 244, p. 622-642.

———— **and Albritton, C. C.** (1943); *Soil phenomena as evidence of climatic changes.* Am. Jour. Sci., 4th Ser., vol. 241, p. 469-490.

———— **and Cady, R. C.** (1934); *The Pleistocene climate of Bermuda.* Am. Jour. Sci., 4th Ser., vol. 27, p. 241-264.

————**, Cleaves, A. B. and Smith, H. T. U.** (1933); *The present status of the Appalachian problem.* Zeitschr. f. Geomorphologie, Bd. 7, H. 6, p. 312-320.

Büdel, J. (1937); *Eiszeitliche und Rezente verwitterung und abtragung im ehemals nicht vereisten teil mittel-europas.* Pet. Mitt., Erg., Nr. 229, 71 p., 26 ill.

Buell, M. F. (1946); *The age of Jerome Bog, "a Carolina Bay".* Science, vol. 103, no. 2662, p. 14-15.

Cain, S. A. (1944); *Pollen analysis of some buried soils, Spartanburg County, South Carolina.* Bull. Torrey Botanical Club, vol. 71, no. 1, p. 11-22.

Cairnes, D. D. (1912); *Differential erosion and equiplanation in portions of Yukon and Alaska.* Geol. Soc. Am. Bull., vol. 23, p. 333-348.

Campbell, M. R. (1903); *Geographic development of northern Pennsylvania and southern New York.* Geol. Soc. Am. Bull., vol. 14, p. 227-296.

————(1929); *Late geologic deformation of the Appalachian Piedmont as determined by river gravels.* Proc. Nat. Acad. Sci., vol. 15, no. 2, p. 156-161.

————(1933); *Chambersburg (Harrisburg) Peneplain in the Piedmont of Maryland and Pennsylvania.* Geol. Soc. Am. Bull., vol. 44, p. 553-573.

Chapman, V. J. (1940); *The botany of the Jamaica shoreline.* Geogr. Jour., vol. 96, no. 5, p. 312-323.

Cole, W. S. (1941); *Nomenclature and correlation of Appalachian erosion surfaces.* Jour. Geol., vol. 49, no. 2, p. 129-148.

Collet, L. (1925); *Les. lacs.* Paris, Octave Doin, 320 p.

Conrad, V. (1942); *Fundamentals of physical climatology.* Cambridge, Harvard Univ. Press, 121 p., 60 ill.

Daly, R. A. (1934); *The changing world of the ice age.* New Haven, Yale Univ. Press, 271 p., 134 ill.

Darton, N. H. (1914); *Some features of the Quaternary deposits in the Wyoming Valley region (Pa.).* Wyoming (Pa.) Hist.-Geol. Soc. Proc., vol. 13, p. 41-64.

Darwin, C. (1839); *Narrative of the surveying voyages of His Majesty's Ships Adventure and Beagle, between the years 1826 and 1836, describing their examination of the southern shores of South America and the Beagle's circumnavigation of the globe.* London, Colburn, vol. 3, p. 254-255.

Davis, J. H. (1946); *The peat deposits of Florida, their occurrence, development and uses.* Fla. Geol. Surv. Bull. No. 30, 240 p., 36 ill.

Davis, W. M. (1889); *Rivers and valleys of Pennsylvania.* Nat. Geog. Mag., vol. 1, p. 183-253.

————(1896); *April recess excursion to the middle Susquehanna, Pa.* Science, n. s., vol. 3, p. 786-787.

De la Beche, H. (1839); *Report on the geology of Cornwall, Devon, and West Somerset.* London, 648 p., 12 maps.

Denny, C. S. (1938); *Glacial geology of the Black Rock Forest.* The Black Rock Forest Bull., No. 8, p. 1-70.

Dorsey, H. G., Jr. (1945); *Some meteorological aspects of the Greenland ice cap.* Jour. Met., vol. 2, no. 3, p. 135-142.

Dücker, A. (1937); *Über strukturboden im Riesengebirge. Ein beitrag zum bodenfrost- und lössproblem.* Z. deutsch. geol. Ges., Berlin, vol. 89, p. 113-129.

Eargle, D. H. (1940); *The relations of soils and surface in the South Carolina Piedmont.* Science, vol. 91, no. 2362, p. 337-338.

Fergusson, S. P., Editor (1931); *Reports of the Greenland expeditions of the University of Michigan (1926-1931) Part I, Aerology, expeditions of 1926 and 1927-29.* Univ. of Mich. Press, 259 p., 53 ill.

Flint, R. F. (1947); *Glacial geology and the Pleistocene epoch.* New York, Wiley, 575 p., 88 ill., 6 pl.

Fridley, H. M. (1929); *Identification of erosion surfaces in south-central New York.* Jour. Geol., vol. 37, p. 113-134.

Friedkin, J. F. and others (1945); *A laboratory study of the meandering of alluvial rivers.* U. S. Waterways Exp. Sta., Vicksburg, 40 p., 61 pl.

Fuller, M. L. and Alden, W. C. (1903-A); *Description of the Gaines quadrangle.* U. S. Geol. Surv. Folio 92, 9 p., maps.

——————(1903-B); *Description of the Elkland and Tioga quadrangles.* U. S. Geol. Surv. Folio 93, 9 p., maps.

Geikie, J. (1895); *The great ice age.* London, Stanford, 3rd ed., 850 p., 18 pl., 78 ill.

Gilbert, B. D., Cobb, W. B., Moffitt, E. L., and Cox, J. F. (1916); *Soil survey of Lancaster County, Pennsylvania.* U. S. Dept. of Agr., Bur. Soils, 70 p., map.

Godwin-Austen, R. A. C. (1851); *On the superficial accumulations of the coasts of the English Channel, and the changes they indicate.* Quart. Jour. Geol. Soc. London, vol. 7, p. 118-136.

——————(1857); *On the newer Tertiary deposits of the Sussex coast.* Quart. Jour. Geol. Soc. London, vol. 13, p. 40-72.

Harrison, H. T. (1931); *Antarctic meteorology.* Monthly Weather Review, vol. 59, no. 2, p. 70-73.

Haurwitz, B. (1941); *Dynamic meteorology.* New York, McGraw-Hill, 365 p., 89 ill.

Hendrickson, B. H., Burke, R. T. A., Goodman, K. V., and Smith, R. L. (1929); *Soil survey of Wyoming County, Pennsylvania.* U. S. Dept. Agr., Bur. Chem. & Soils, ser. 1929, No. 34, 36 p., 1 pl., map.

Hickok, W. O. IV (1933); *Erosion surfaces in south-central Pennsylvania.* Am. Jour. Sci., 5th ser., vol. 25, no. 146, p. 101-122.

Higbee, H. W., Bacon, S. R., Burke, R. T. A., Patrick, A. L., Brown, L. A., Tedrow, N. P., Long, R. S., and Atkinson, C. H. (1944); *Soil survey of Huntingdon County, Pennsylvania.* U. S. Dept. Agr., Bur. Plant Ind., Soils, and Agr. Eng., ser. 1934, No. 27, 144 p., 10 pl., map.

Hill, F. A. (1886); *Description of the Wyoming buried valley between Pittston and Kingston.* Ann. Rpt. Geol. Surv. Penn. for 1885, p. 637-647.

Hobbs, W. H. (1931); *Loess, pebble bands, and boulders from glacial outwash of the Greenland continental glacier.* Jour. Geol., vol. 39, no. 4, p. 381-385.

——————(1945); *The Greenland glacial anticyclone.* Jour. Met., vol. 2, no. 3, p. 143-153.

Högbom, B. (1913); *Über die geologische bedeutung des frostes.* Bull. Geol. Inst. Upsala, vol. 12, p. 257-389.

——————(1926); *Beobachtungen aus Nordschweden über den frost als geologischer faktor.* Bull. Geol. Inst. Upsala, vol. 20, p. 243-279.

Howard, E. B. (1934); *Grooved spearpoints.* Pennsylvania Archaeologist, vol. 3, no. 6, p. 11-15.

——————(1942); *A "fluted point" site in Pennsylvania.* Pennsylvania Archaeologist, vol. 12, no. 1, p. 4-6.

Itter, H. A. (1938); *The geomorphology of the Wyoming-Lackawanna region.* Pa. Geol. Surv., 4th ser., Bull. G-9, 82 p.

Johnson, D. W. (1931); *Stream sculpture on the Atlantic slope, a study in the evolution of Appalachian rivers.* New York, Columbia Univ. Press. 142 p., 21 ill.

Klemm, G. (1918); *Über die entstehung der "felsenmeere" des Felsberges und anderer orte im Odenwalde.* Notizbl. d. Ver. f. Erdk. U. D. Grossh. Geol. Landesanstalt zu Darmstadt f. d. Jahr 1917, v. Folge., H. 3, p. 3-11.

Klute, F. (1927); *Die oberflachenformen der Arktis: morphologie der klimazonen.* Dusseldorfer Geogr. Vortrage und Erorterungen, p. 91-99.

————(1928); *The significance of the depression of the snow-line in Pleistocene problems.* Z. f. Gletscherkunde, Bd. 16, p. 70-93.

————(1937); *Eiszeit und klima.* Frankfurter Geogr. Heften, 11th Jahrg., p. 56-63.

Knopf, E. B. (1924); *Correlation of residual erosion surfaces in the eastern Appalachian highlands.* Geol. Soc. Am. Bull., vol. 35, p. 633-668.

Köppen, W. and Wegener, A. (1924); *Die klimate der geologischen vorzeit.* Berlin, Geb. Borntraeger, 255 p., 41 ill.

Leffingwell, E. deK. (1915); *Ground-ice wedges; the dominant form of ground ice on the north coast of Alaska.* Jour. Geol., vol. 23, p. 635-654.

Leighton, M. M. (1931); *The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley.* Jour. Geol. vol. 39, no. 1, p. 45-53.

———— **and MacClintock, P.** (1930); *Weathered zones of the drift-sheets of Illinois.* Jour. Geol., vol. 38, no. 1, p. 28-53.

Lesley, J. P. (1884); *Letter of transmittal.* Pa. Second Geol. Surv., vol. Z, p. v-xlix.

Leverett, F. (1902); *Glacial formations and drainage features of the Erie and Ohio Basins.* U. S. Geol. Surv., Mono. no. 41, 802 p., maps.

———— **and Taylor, F. B.** (1915); *The Pleistocene of Indiana and Michigan and the history of the Great Lakes.* U. S. Geol. Surv., Mono. no. 53, 529 p., maps.

————(1934); *Glacial deposits outside the Wisconsin terminal moraine in Pennsylvania.* Pa. Geol. Surv., 4th Ser., Bull. G-7, 123 p., 38 ill.

Lewis, H. C. (1884); *Report on the terminal moraine in Pennsylvania and western New York.* Pa. Second Geol. Surv., vol. Z, 299 p.

Lewis, W. V. (1936); *Nivation, river grading, and shore-line development in south-east Iceland.* Geog. Jour., London, vol. 88, no. 5, p. 431-447.

————(1944); *Stream trough experiments and terrace formation.* Geol. Mag., vol. 81, no. 6, p. 241-253.

————(1945); *Nick points and the curve of water erosion.* Geol. Mag., vol. 82, no. 6, p. 256-266.

Lozinski, W. von (1909); *Über die mechanische verwitterung der sandsteine im gemässigten klima.* Bull. Acad. Sci. de Craconie, Cl. des Sci. Math. et Nat., p. 1-25.

————(1933); *Palsen fields and periglacial soil formation.* Neues Jahrb. f. Min., Bd. 71, Abt. B., p. 18-47.

MacClintock, P. (1940); *Weathering of the Jerseyan till.* Geol. Soc. Am. Bull., vol. 51, no. 1, p. 103-115.

———— **and Apfel, E. T.** (1944); *Correlation of the drifts of the Salamanca Re-entrant, New York.* Geol. Soc. Am. Bull., vol 55, p. 1143-1164.

Mackin, J. H. (1933); *The evolution of the Hudson-Delaware-Susquehanna drainage.* Am. Jour. Sci.. 5th Ser., vol. 26, no. 153, p. 319-331.

————(1934); *Terraces in the Susquehanna Valley below Harrisburg. Pa.* Science, n. s., vol. 80, no. 2067, p. 140-141.

————(1936); *Susquehanna river terraces.* Cong. internat. geographie Warsaw, 1934, Trav. Sec. II, T. 2, p. 524-528.

Mantell, G. (1833); *Geology of the south-east of England.* London, 415 p., 5 pl.

Matthes, F. E. (1946); *Report of committee on glaciers, 1945.* Trans. Am. Geophysical Union, vol. 27, no. 2, p. 219-233.

Meinardus, W. (1909); *Die mutmassliche mittlere höhe des Antarktischen kontinents.* Pet. Mitt., vol. 55, p. 304-309, 355-360.

Meyer, H. (1904); *Die Eiszeit in den tropen.* Geogr. Zeitschr., vol. 10, p. 593-600.

Movius, H. L., Jr. (1944); *Early man and Pleistocene stratigraphy in southern and eastern Asia.* Harvard Univ., Peabody Mus. Am. Archaeology, Papers vol. 19, no. 3, 125 p., 47 ill.

Nilsson, E. (1935); *Traces of ancient changes of climate in East Africa.* Meddelanden fran Stockholms Hogskolas Geologiska Institut, no. 36, Geogr. Annaler, H. 1-2.

Penck, A. and Brückner, E. (1909); *Die Alpen im Eiszeitalter.* Leipzig, Tauchnitz, (3 vols.), 1199 p.

Poser, H. (1936); *Talstudien aus Westspitzbergen und ost Grönland.* Zeitschr. f. Gletscherkunde, Bd. 24, p. 43-98, 15 ill.

Potzger, J. E. and Tharp, B. C. (1943); *Pollen record of Canadian spruce and fir from Texas bog.* Science, vol. 98, no. 2557, p. 584.

———— **and Tharp, B. C.** (1947); *Pollen profile from a Texas bog.* Ecology, vol. 28, no. 3, p. 274-280.

Prestwich, J. (1892); *The raised beaches, and "head" or rubble drift of the south of England; their relation to the valley drifts and to the glacial period; and on late post-glacial submergence.* Quart. Jour. Geol. Soc. London, vol. 48, p. 263-343.

Quiring, H. (1928); *Neue beiträge zur geologie des Siegerlandes und Westerwaldes. I. Die periglazialen blockströme (erdgletscher) am nordrand des hohen Westerwaldes.* Jahrb. Preuss. Geol. Landesanstalt, Bd. 48, p. 619-633.

Reid, C. (1892); *The Pleistocene deposits of the Sussex coast, and their equivalents in other districts.* Quart. Jour. Geol. Soc. London, vol. 48, p. 344-364.

Richards, H. G. (1931); *The subway tree—A record of a Pleistocene cypress swamp in Philadelphia.* Bartonia, vol. 13, p. 1-6.

————(1944); *Notes on the geology and paleontology of the Cape May Canal, N. J.* Notulae Naturae of Acad. Nat. Sci. Philadelphia, no. 134, p. 1-12.

Salomon, W. (1929); *Arktische bodenformen in den Alpen.* Heidelberger Akad. d. Wiss. (Math-Naturw. kl.), p. 1-31.

Shaeffer, C. E. (1941); *Folsom points in early Pennsylvania collections.* Pennsylvania Archaeologist, vol. 11, no. 3, p. 62.

Schott, C. (1931); *Die blockmeere in den Deutschen Mittelgebirgen.* Stuttgart, Engelhorns, 78 p., 16 pl.

Shaw, C. F., Byers, W. C., and Ross, W. G. (1912); *Reconnaissance soil survey of south-central Pennsylvania.* U. S. Dept. Agr., Bur. Soils, 12th Rpt. 1910 Field Op., p. 193-265.

————, **McKee, J. M. and Ross, W. C.** (1914); *Reconnaissance soil survey of northeastern Pennsylvania.* U. S. Dept. Agr., Bur. Soils, 13th Rpt. Field Op., p. 269-327.

————, **McKee, J. M. and Ross, W. G.** (1915); *Reconnaissance soil survey of southeastern Pennsylvania.* U. S. Dept. Agr., Bur. Soils, 14th Rpt. 1912 Field Op., p. 247-340.

Simpson, G. C. (1940); *Possible causes of change in climate and their limitations.* Proc. Linn. Soc. London, vol. 152, p. 190-219.

Smith, H. T. U. (1941); *Periglacial features in the driftless area of southern Wisconsin.* (Abstr.) Geol. Soc. Am. Bull., vol. 52, p. 1934.

———— **and Smith, A. P.** (1945); *Periglacial rock streams in the Blue Ridge area.* (Abstr.) Geol. Soc. Am. Bull., vol. 56, p. 1198.

Soergel, W. (1924); *Die Diluvialen terrassen der Ilm und ihre bedeutung für die gliederung des Eiszeitalters.* Jena, Fischer, 76 p., 7 ill.

Starr, V. P. (1942); *Basic principles of weather forecasting.* New York, Harper, 299 p., 125 ill.

Steche, H. (1933); *Beiträge zur frage der strukturboden.* Ber. verhandl. d. Sach. Akad. d. Wissensch. z. Leipzig (Math.-Phys. kl.), vol. 85, p. 193-250, 39 ill., bibl.

Stevens, E. H., Hendrickson, B. H., Manifold, C. B., Degan, C. G., and Patrick, A. L. (1923); *Soil survey of Lycoming County, Pennsylvania.* U. S. Dept. Agr., Bur. Chem. & Soils, no. 32, p. 1043-1093, map.

Stewart, T. B. (1938); *Archeology of the West Branch. A Report of the Susquehanna River Expedition.* p. 76-88, Andover Press.

Stose, G. W. (1928); *High gravels of Susquehanna River above Columbia, Pennsylvania.* Geol. Soc. Am. Bull., vol. 39, no. 4, p. 1073-1086.

Strahler, A. N. (1945); *Hypothesis of stream development in the folded Appalachians of Pennsylvania.* Geol. Soc. Am. Bull., vol. 56, no. 1, p. 45-87.

Sverdrup, H. U. (1942); *Oceanography for meteorologists.* New York, Prentice-Hall, 235 p., 69 ill.

Tollner, H. (1931); *Gletscherwinde in den Ostalpen.* Meteorologische Zeitschrift, Bd. 48, H. 11, p. 414-421.

United States Geological Survey (1937); *Floods of March 1936, Pt. 2, Hudson River to Susquehanna River region.* Water Supply Paper 799, 380 p.

Ver Steeg, K. (1930); *Wind gaps and water gaps of the northern Appalachians, their characteristics and significance.* Ann. N. Y. Acad. Sci., vol. 32, p. 87-220.

Wegener, K. (1939); *Wissenschaftliche ergebnisse der Deutschen Grönland-expedition Alfred Wegener 1929 und 1930/1931.* Leipsic, Brockhaus, Bd. IV Meteorologie, 380 p.

Wentworth, C. K. (1928); *Striated cobbles in southern states.* Geol. Soc. Am. Bull., vol. 39, no. 4, p. 941-954.

White, I. C. (1883); *Report on the geology of Wyoming, Lackawanna, Luzerne, Columbia, Montour and Northumberland Counties.* Pa. Second Geol. Surv., vol. G-7, 464 p., maps.

Williams, E. H. (1895); *Notes on the southern ice limit in eastern Pennsylvania.* Am. Jour. Sci., vol. 49, p. 174-185.

———————(1898); *Notes on Kansan drift in Pennsylvania.* Am. Phil. Soc. Proc., vol. 37, no. 157, p. 84-87.

———————(1902); *Kansan glaciation and its effects on the river systems of northern Pennsylvania.* Wyoming (Pa.) Hist.-Geol. Soc. Proc., vol. 7, p. 21-28

———————(1917); *Pennsylvania glaciation, first phase.* Woodstock, Vt., 101 p. 56 ill.

Wood, P. O., McKee, J. M., Skemp, L. M., Nissley, W. B., and Dickey, J. B. R. (1914); *Soil survey of Bradford County, Pennsylvania.* U. S. Dept. Agr., Bur. Soils, 13th Rpt. Field Op., p. 231-267.

Woodworth, J. B. (1905); *Ancient water levels of the Champlain and Hudson Valleys.* N. Y. State Mus. Bull., no. 84, 265 p.

Wright, G. F. (1884); *The glacial boundary in Ohio, Indiana and Kentucky.* Pa. Second Geol. Surv., Report Z, p. 203-243.

———————(1892); *Extramorainic drift in the Susquehanna, Lehigh and Delaware Valleys.* Proc. Acad. Nat. Sci. Philadelphia.

Zeuner, F. E. (1945); *The Pleistocene period, its climate, chronology and faunal successions.* Ray Soc. London, 322 p., 76 ill.

INDEX

Geographic Index

A

Adirondack Mountains; 18, 19.
Alabama; 133, 138.
Allegheny Front; 22, 75.
Anderson; 64.
Appalachian Mountains; 1, 132, 137.
Appalachian Plateau; 17, 18, 21, 25, 75, 79, 81, 82.
Arctic and Antarctic regions; 48, 136.
Ardenheim; 120.
Asylum; 83.
Athens; 86-89.
Atlantic Ocean; 134, 135, 136.
Azores region; 134.

B

Bald Eagle Mountain; 26, 60, 71-74, 97-98, 101, 103.
Bald Mountain; 75.
Baltimore, Md.; 138.
Beach Haven; 24, 25.
Belvidere, N. J.; 20.
Berry Mountain; 108, 121.
Berwick; 13-14, 20, 24, 25, 26, 54, 84, 91-97, 110.
Big Mountain; 69.
Binghamton, N. Y.; 16.
Bloomsburg; 76, 84.
Blue Mountain; 45, 70, 108, 121.
Blue Ridge; 137.
Buck Creek; 89.
Buffalo Creek; 66, 107.
Buffalo Mountain; 121.

C

Canada; 134, 136.
Catawissa; 68, 69, 79.
Catawissa Creek; 76.
Catskill Mountains; 1, 18, 20.
Cattaraugus Creek; 15.
Cayuta Creek; 86, 87.
Cedar Spring Run; 129, 131.
Charlton; 27, 61.
Chatham Run; 27.
Chemung River; 2, 15, 19, 23, 38, 52, 75, 76, 78, 86-88.
Chesapeake Bay; 109, 119-120.
Chickies Ridge; 108-109, 111.
Chillisquaque; 49, 51.
Clear Ridge; 120.
Coastal Plain; 115.
Conewago Falls; 109, 110, 111, 112, 116-117.
Conoy Creek; 67.
Craigtown, Md.; 111.

D

Danville; 65, 67, 76, 84, 110.
Dauphin; 108.
Delaware; 138.
Delaware River; 25.
Dewart; 17, 28, 103.
Dunnstown; 55.

E

East Lemon; 25, 40, 47.
East Towanda; 52-53, 75.
Elizabethtown; 67.
Elmira, N. Y.; 81.
England; 48.
English Center; 26.

F

Fairfield; 100.
Falls; 39, 54, 75, 84, 110.
Field; 26.
Florida; 133, 138.
Forkston; 23, 24, 57.
Fort Hunter; 108, 116.
Forty Fort; 39.

G

Georgia; 132, 136.
Greenes Landing; 19, 81, 86.
Greenland; 136, 140.
Gulf of Mexico; 135-136.
Gulf Stream; 135.

H

Half Falls; 112.
Harrisburg; 110, 111, 112, 113, 115-120.
Havre de Grace, Md.; 2.
Herndon; 59-60.
Hicks Ferry; 92-93.
Highspire; 110, 111, 116, 117-118.
Hooflander Mountain; 108.
Hornbrook; 38.
Hudson Bay; 138.
Hudson River; 18, 20, 24, 25, 139.
Hudson River Highlands; 6.
Hunlock Creek; 94.
Huntingdon; 122.

I

Illinois; 132.
Indiana; 132.

J

Jacks Mountain; 56, 62-64, 70, 120, 121.
James River; 137.
Juniata River; 2, 10, 13, 46, 52, 56, 64, 110, 118, 120-131.

K

Knob Mountain; 76.

L

Lackawanna River; 2, 20, 23, 75, 79, 95.
Laporte; 74.
Larrys Creek; 11.
Lee Mountain; 76.
Lehigh River; 15.
Lewisburg; 27, 100, 107.
Lewistown; 64, 121.
Lewistown Narrows; 70-71, 121.
Lime Ridge; 84.
Little Fishing Creek; 26.
Little Mountain; 68-69.
Little Muncy Creek; 100, 105.
Little Pine Creek; 26.
Liverpool; 108.
Lloyd; 101.
Lock Haven; 2, 97, 101, 103.
Locust Run; 129.
Losh Run; 64-65, 122.
Loyalsock Creek; 26, 100, 105.
Luzerne; 21, 22, 41.
Lycoming Creek; 26, 103, 105.

M

Macedonia; 121.
Mahantango; 49.
Mahoning Creek; 65.
Mapleton; 38, 56, 62, 70, 120.
Marietta; 2, 10, 37, 45, 55, 108, 112, 119.
Maryland; 138.
McKee Half Falls; 108.
McKune; 93.
McVeytown; 124-125.
Mehoopany; 89.
Mehoopany Creek; 21, 22, 24, 57.
Meshoppen; 25, 97.
Mexico; 129, 130.
Middle Creek; 113.
Middletown; 118.
Mifflintown; 46, 127-131.
Milan; 19, 86, 90.
Mill Creek; 95.
Millersburg; 49, 55, 60, 112.
Millerstown; 121-122, 131.
Milton; 49, 67.
Miners Mills; 95.
Mississippi Valley; 16-17, 48, 56, 119.
Mohawk River; 18, 21.
Mantandon; 107.
Montgomery; 60, 98, 100, 103, 105.
Montour Mountain; 27, 28, 65-66, 98, 101.
Montoursville; 71, 101, 105, 106.
Mount Patrick; 108.
Mount Pleasant; 130.
Mount Union; 121, 122, 123, 124, 125-126.
Moosic; 95.
Muncy; 74, 101, 103-106.
Muncy Creek; 100, 101, 105.
Muncy Hills; 26, 98, 103.
Murray Creek; 19.

N

Nanticoke; 76, 93.
Nescopeck Mountain; 76.
New Buffalo; 61, 111.
New Columbia; 43, 56, 66.
New Jersey; 32.
Newport; 121, 123.
Newton Hamilton; 121.
New York; 15, 18, 22.
North Branch, Susquehanna River; 2, 15, 18, 20, 38, 52, 75-97, 99-100, 109, 114.
North Carolina; 14, 133, 138.
North Mehoopany; 21, 25.
North Towanda; 57.
Northumberland; 82, 84, 97, 100, 108, 111, 112.

O

Old Forge; 95.
Olean, N. Y.; 20.
Ontario; 18, 138.
Osterhout; 96.
Otto, N. Y.; 15.

P

Pacific Ocean; 135, 136.
Parsons; 95.
Paxton Creek; 112, 116, 119.
Penns Creek; 29, 113, 115.
Pennsylvania; 15, 17-18, 20, 21, 26.
Penny Hill; 28, 32.
Penobscot Mountain; 76.
Philadelphia; 138.
Picture Rocks; 101.
Piedmont; 109, 137.
Pine Creek; 27, 101.
Pittstown; 82.
Plymouth; 76, 92.
Port Royal; 127, 130.
Port Trevorton; 114, 115, 119.
Potomac River; 137.

R

Ramsey School; 66.
Rhine River; 48.
Rohrsburg; 26.

S

Satterlee Creek; 89.
Sayre; 87.
Scottsville; 89.
Second Mountain; 108.
Selinsgrove; 17, 26, 27, 28, 33, 44-45, 55, 56, 100, 109, 111, 113-115, 125.
Shade Mountain; 70, 121.
Shickshinny; 54, 76, 94.
Shocks Mills; 118.
South Carolina; 133.
Spanish Hill; 52.
Spencer Lake; 81.
Sugar Creek; 21, 24, 42, 57.
Sunbury; 108, 112, 113.
Susquehanna River; 52, 59, 84, 108-120, 122, 125.
Swatara Creek; 118.

T

Tennessee River; 137.
Terrace Mountain; 120.
Texas; 133, 138.
Thompsontown; 46, 128-129, 131.
Tioga Point; 88.
Tioga River; 2.
Tomb; 27.
Towanda; 75.
Tunkhannock Creek; 40.
Turkey Run; 104.
Tuscarora; 121, 124.
Tuscarora Mountain; 121.

V

Vandyke; 123, 130.
Vineyard; 63, 121.
Virginia; 14, 138, 140.
Vosburg; 58-59.

W

Watsontown; 26, 27, 28, 98.
Waverly, N. Y.; 2, 75, 86, 90.
West Branch, Susquehanna River; 15, 17, 20, 26-27, 28, 32, 38, 52, 75, 76, 84, 88, 97-107, 109, 114, 123.
West Pittston; 77, 110.
White Deer Creek; 27, 98.
Wiconisco Creek; 49.
Williamsport; 26, 27.
Wilmot; 89.
Winfield; 26.
Wyalusing; 75, 84, 89.
Wyalusing Creek; 89.
Wyoming Valley; 75-76, 80, 82, 97.
Wysox; 77, 79, 87, 97.

SUBJECT INDEX

A

- abandoned valley; 76.
- age
  - boulder-strewn slopes; 70, 72.
  - dune sand; 7, 51.
  - loess; 7.
  - rubble; 58-59, 60-61.
  - soils; 38-46.
  - terraces; 15-17, 100.
- air temperature; 131-132, 135-136.
- alluvial fan; 88, 89, 105.
- amount of weathering; 30-31, 32-33.
- atmospheric circulation; 131-132, 135-136.
- autopiracy; 76.

B

- Barbour soil series; 36.
- bench, rock; 1, 13, 75, 107, 109, 112, 114-115, 119, 122-123, 125, 126-127, 129.
- Binghamton
  - glacial deposits; 19-20.
    - composition, lithologic; 19.
    - extent; 15, 19.
    - frontal kames; 86, 87.
    - kame gravel; 20.
    - terminal moraine; 19, 86.
    - till; 19-20.
    - topography; 15, 86.
    - weathering; 15, 19.
  - gravel; 83.
  - loess; 52.
  - terraces
    - kame terraces; 86-87.
    - periglacial terraces; 83, 86, 88-89, 99, 101, 103, 106, 107, 110, 113-114, 116-117, 123, 124, 127, 131.
    - valley train terraces; 77, 81-82, 86, 87-88.
- birch; 133.
- blockfields; 73-74.
  - boulders; 73.
  - morphology; 73, 74.
  - origin; 73-74.
  - size; 73.
  - structure; 73.
  - weathering; 73, 74.
- Bloomsburg; 34, 67, 107, 129.
- boulder-strewn slopes; 5, 69-73.
  - age; 70, 72.
  - boulders; 69, 71, 72-73.
  - erosion of; 6, 68, 71.
  - origin; 67, 71.
  - profile; 5, 48, 60-61, 67-68, 69, 71.
  - soils; 6, 45, 72.
  - stability; 5-6.
- boulder zone; 62-63, 65.
- boulders
  - in blockfields; 73.
  - on boulder-strewn slopes; 69, 71, 72-73.
- Brandywine; 120.
- buried loess; 63.
- buried soil; 36, 63, 117.
- buried valley; 75-76.

C

- Cary (see Valley Heads)
- "Catskill"; 20, 21, 23.
- cedar; 132.
- channel losses; 8-9, 82.
- Chenango soil series; 40, 54.
- chert
  - occurrence; 2, 78, 79, 104, 128, 130.
  - weathering; 35.
- classification of soils; 35-38.
- clay; 19, 28, 29, 38, 62, 64, 86, 93, 95, 105, 117.
- climate; 14-15, 131-139.
  - cycles; 2, 14, 15, 131-132, 139, 140.
  - glacial; 9-10, 14-15, 134-138, 138-139, 140.
  - interglacial; 7, 14, 138.
  - mesothermal; 138.
  - microthermal; 138.
- coal; 113.
- Coastal Plain; 2, 115, 119-120.
- composite soils; 39-44, 47.
- composite terraces; 36, 101, 105-106, 116-117, 123, 124, 125, 126.
- composition
  - glacial deposits; 17-18.
    - Binghamton; 19.
    - Illinoian; 27, 114.
    - Olean; 20-22, 103-104.
  - periglacial gravel; 122.
  - rubble; 6.
  - valley train gravel; 78-79, 99, 103-104, 113.
- concretions; 93.
- congelifraction; 7, 59, 67-69.
- congeliturbation (see rubble); 7, 18, 27-28, 30, 38, 43, 48, 49, 56-74.
- conglomerate, weathering of; 33.
- continental ice; 132.
- correlation
  - glacial deposits; 3-4, 15-17.
  - nickpoints; 131.
  - terraces; 10-13, 13, 78, 79, 81, 83, 83-84, 100, 101-103.
- crest of flood; 8, 110.
- cross-section profile; 11-12.
- cryoplanation; 18-19, 30, 67-69.
- culm; 38, 80.
- cycles, climatic; 2, 14, 15, 131-132, 139, 140.
- cypress; 138.

D

- definition
  - congelifraction; 7.
  - congeliturbation; 7.
  - cryoplanation; 30.
  - kame gravel; 23.
  - mollisol; 64.
  - pergelisol; 64.
  - periglacial gravel; 6.
  - periglacial zone; 137.

  polygenetic soil; 41.
  rubble; 5.
  terrace; 1.
  valley train gravel; 23.
Dekalb soil series; 38.
delta of Susquehanna River; 120.
depressions; 17, 49, 129-130.
Devonian; 18, 29, 64, 104.
diabase; 108, 109.
diastrophism; 13-14, 82.
drawdown curve; 100, 106, 116.
dune sand; 7, 48, 49-51, 107.
  age; 7, 51.
  erosion; 49.
  origin; 7, 136, 137.
  soils; 49.
  topography; 49.

E

Early Illinoian; 109, 111, 114, 118, 123, 126, 128-129.
Elk soil series; 37, 45.
erosion
  boulder-strewn slopes; 6, 68, 71.
  channel; 10, 19, 84, 90, 105, 111, 121, 125, 139.
  dune sand; 49.
  lateral; 11, 79, 110, 115, 122-123.

F

felsite; 24.
feretto zone; 42.
fir; 133.
floods
  modern; 8-9, 80, 99, 131.
    channel storage; 8-9, 82.
    crest; 8, 110.
    profile; 8-9.
  Pleistocene; 9-10, 77, 81-82, 94, 96, 105, 138.
    gradient; 9, 82-83.
    load; 9-10, 80, 82-83.
    origin; 9-10, 138.
formation
  Bloomsburg; 34, 67, 107, 129.
  "Catskill"; 20, 21, 23.
  Devonian; 18, 29, 64, 104.
  Hamilton; 104.
  Juniata; 69, 73, 104.
  Marcellus; 104, 107.
  Mauch Chunk; 34.
  Mississippian; 69, 104, 129.
  "Montebello"; 49.
  Ordovician; 69, 104, 129.
  Oriskany; 104.
  Pennsylvanian; 69.
  Pocono; 20, 68, 69, 74.
  Pottsville; 20, 69.
  Rose Hill; 65, 66, 104, 125.
  Shawangunk; 45.
  Silurian; 34, 62, 67, 69, 71, 104.
  Tuscarora; 45, 60, 69, 71, 73, 104.
  Wills Creek; 104, 107.
fossil
  plants; 132-134, 138.
  soils; 36, 63, 117.
freezing; 6, 60, 137.
"fringe"; 26.
frost action; 20, 28, 51, 65, 67-68, 73-74, 99.
frost heaving; 10, 24, 57, 65, 67.
frost splitting; 49, 67-68, 73-74.
frost wedges; 53.
frozen ground; 6, 10.

G

Genesee soil series; 36.
Gilpin soil series; 38.
glacial deposits; 15-30.
  Binghamton; 19-20.
  Illinoian; 26-30.
  Olean; 20-26.
  pre-Illinoian; 30.
  soils; 38-45.
gneiss; 18, 19, 21, 24, 32-33, 78, 79, 99, 118, 119.
gradient
  floods; 9, 82-83.
  frontal kames; 87, 91-92, 96.
  kame terraces; 95-96.
  rock benches; 112, 119.
  valley train terraces; 87, 92, 96.
granite; 2, 3, 18, 19, 30, 32-33, 78, 79, 99, 109, 110, 113, 117, 118, 119, 122.
  weathering; 32-33.
gravel; 5, 9-10, 13, 17, 23-24, 25, 27-28, 28-30, 76, 80, 92, 101, 103-104, 107.
  Binghamton; 83.
  economic value; 2.
  Illinoian; 27, 84, 114-115.
  kame; 20, 23-24, 28, 76.
  lithology; 79, 83-84, 99, 110.
  mixing; 78-79.
  moraines; 23-24, 25.
  Olean; 20-22, 83-84, 103-104.
  periglacial; 122, 123, 127, 128-129.
  significance; 15, 90.
  soils; 38-40, 45-47.
  sorting; 9-10, 81, 83, 92, 93-94.
  transportation; 1, 4-5, 9-10, 80, 84, 95-96, 109.
  Valley Heads; 38.
  valley train; 23, 78-79, 99, 103-104, 113.
  weathering; 17.
gravel cap; 93-96.

H

Hamburg and Marilla moraines; 4.
Hamilton; 104.
Harrisburg peneplain; 60, 64, 76, 112.
heaving, frost; 10, 24, 57, 65, 69.
height of terraces; 1, 10-11, 11, 77-78, 79, 81, 81-83, 84, 86-87, 91, 92, 93, 95, 96, 99, 100-101, 107, 109-112, 114-115, 122-123, 123, 124, 125, 126.
hemlock; 133.
Highspire terrace; 109, 111, 118.
hinge line; 82.

Holston soil series; 38, 46.
Hudson Valley ice; 18, 20, 25, 139.
Huntington soil series; 36, 38.
hydraulic jump; 116.

I

ice-contact gravel; 20, 23-24, 28, 76.
ice, continental; 132.
ice-front lake; 18, 86, 93, 95.
ice front slope; 25-26.
igneous rocks; 18, 20, 21, 24, 25.
Illinoian
  glacial deposits; 26-30.
    extent; 15, 26-28.
    ice-contact gravel; 28, 76.
    kame terrace; 101, 104.
    lithology; 27, 114.
    occurrence; 26.
    terminal moraine; 26-28, 28-30, 113, 114.
    till; 28.
    topography; 17, 27, 28-30.
    weathering; 17, 26.
  gravel; 27, 84, 114-115.
  loess; 55-56.
  rubble; 27, 61.
  terraces; 84, 99, 101-103, 104, 107.
    Early Illinoian; 109, 111, 114, 118, 123, 126, 128-129.
    Late Illinoian; 109, 111, 114, 118, 123, 125-126, 127, 128-129.
interglacial climate; 7, 14, 138.
Ilwan (see Olean)

J

jointing
  congeliturbate; 57.
  loess; 51.
  till; 23.
jump, hydraulic; 116.
Juniata; 69, 73, 104.
Juniata River terraces; 120-131.
  Binghamton; 123, 124, 127, 131.
  composite terraces; 123, 124, 127.
  Early Illinoian; 123, 126, 128.
  gravel; 123, 127, 128-129.
  height; 122, 123-126,
  Late Illinoian; 123, 125-126, 127, 128-129.
  Locust Run; 123, 129-130.
  Mankato; 123, 123-124.
  Mexico; 123, 129.
  Mount Pleasant; 123, 130.
  Olean; 122, 124-125, 127-128.
  origin; 122, 122-123, 125-126.
  pre-Pleistocene; 122, 123.
  profile; 122, 131.
  Valley Heads; 123, 124.
  Vandyke; 123, 130.

K

kame, frontal
  Binghamton; 86, 87.
  Olean; 25, 90, 91-92, 96-97, 139.
kame gravel; 20, 23-24, 28, 76.
kame terraces; 18, 138, 139.
  Binghamton; 86-87.
  Illinoian; 101, 104.
  Olean; 18, 25, 90, 91-97.
Kansan; 15, 17, 109.

L

Lackawanna soil series; 22.
larch; 132.
Late Illinoian terraces; 109, 111, 114, 118, 123, 125-126, 127, 128-129.
lateral erosion; 11, 79, 110, 115, 122-123.
lateritic soils; 32.
leaching; 4, 42, 47.
liesegangs rings; 74.
limestone; 2, 17, 19, 20, 28, 79, 98, 99, 108, 118, 121, 129-130.
lithology
  glacial deposits; 17-18.
  Binghamton; 19.
  Illinoian; 27, 114.
  Olean; 20-22, 103-104.
  periglacial gravel; 122.
  valley train gravel; 78-79, 99, 103-104, 113-114.
load of streams; 6, 9-10, 80, 82-83.
Locust Run terrace; 123, 129-130.
loess; 6-7, 48, 51-56, 92, 94, 115.
  age; 7.
  Binghamton; 52.
  buried; 63.
  Illinoian; 55-56.
  jointing; 51.
  Olean; 54, 84.
  origin; 6-7, 52, 137.
  pebbly; 24, 51, 58, 78.
  significance; 15.
  soils; 55-56.
  Wisconsin; 126.

M

magnolia; 133.
man, early; 1.
Mankato terraces; 13, 15, 77, 79-80, 99, 100, 103, 107, 109, 113, 116, 123, 123-124.
Manor soil series; 59-60.
Marcelus; 104, 107.
Mauch Chunk; 34.
meanders; 75, 90-91, 120-121.
mesothermal climate; 138.
metamorphic rocks; 20, 21, 24, 25.
methods of study; 10-13, 77-78.
Mexico terrace; 123, 129.
microthermal climate; 138.
migratory nickpoints; 127.
Mississippian; 69, 104, 129.
mixing
  congeliturbate; 58, 63.
  gravel; 78-79.
modern floods; 8-9, 80, 99, 131.
Mohawk Valley ice; 17-18, 20-24, 39, 117.
mollisol; 64, 65-66.
monogenetic soils; 35, 38.
"Montebello"; 49.

- morainal topography; 18-19, 23, 89-90.
- moraine
  - gravel; 23-24, 25.
  - recessional; 89-90.
  - terminal
    - Binghamton; 19, 86.
    - Illinoian; 26-28, 28-30, 113, 114.
    - Olean; 25, 97.
    - Valley Heads; 81.
- morphology of blockfields; 73, 74.
- Moshannon soil series; 36, 38.
- Mount Pleasant terrace; 123, 130.

N

- Nebraskan; 15, 17.
- nickpoints; 75, 76, 84, 89, 98, 100, 103, 105, 108, 109, 116, 121, 122, 123, 124, 127, 131.
  - migratory; 127.
  - origin; 127.
- North Branch, Susquehanna River terraces; 75-97.
  - Binghamton; 77, 81-82, 86, 87-88.
  - gravel; 83-84.
  - height; 77-78, 79, 81, 81-83, 84, 86-87, 91, 92, 93, 95, 06.
  - Illinoian; 84.
  - Mankato; 77, 79-80.
  - Olean; 77, 83-84, 90.
  - profile; 86-87, 92, 96.
  - Valley Heads; 77, 81.
- nunataks; 27.

O

- Olean
  - glacial deposits; 20-26.
    - extent; 15, 20.
    - frontal kames; 25, 90, 91-92, 96-97, 139.
    - kame gravel; 23-24.
    - recessional moraine; 89-90.
    - terminal moraine; 25.
    - till; 21-23, 25.
    - topography; 15, 89-90.
  - gravel; 20-23, 83-84, 103-104.
  - loess; 54, 84.
  - terraces
  - Kame terraces; 25, 91-97.
  - periglacial terraces; 99, 101, 103-104, 105, 107, 110, 114, 117, 122, 124-125, 127-128.
    - valley train terraces; 77, 83-84, 90.
- Ordovician; 69, 104, 129.
- orientation
  - boulders; 57.
  - shale-fragments; 64, 65.
- origin
  - blockfields; 73-74.
  - boulder-streawn slopes; 67, 71.
  - dune sand; 7, 136, 137.
  - loess; 6-7, 52, 137.
  - nickpoints; 127.
  - periglacial terraces; 6, 10, 95-96, 122, 122-123, 125-126.
  - rubble; 5-6, 56, 57, 65.
  - valley train terraces; 1, 13, 77, 79, 139.
- Oriskany; 104.
- outwash plain, pitted; 87.
- oxidation; 7, 42, 47, 53.

P

- path, storm; 132, 135, 136-137, 138.
- Paxton terrace; 112, 119, 123.
- peat; 15, 133.
- pebbles
  - count; 11, 21.
  - erratic; 3, 21, 24.
  - weathering; 32-35.
    - chert; 35.
    - conglomerate; 33.
    - granite; 32-33.
    - quartzite; 33.
    - sandstone; 33-34.
    - shale; 34-35.
    - siltstone; 34.
- pebbly loess; 24, 51, 58, 78.
- Pennsylvanian; 69.
- pergelisol; 64.
- periglacial
  - climate; 6, 7, 136, 137.
  - deposits; 5-7; 48-74, 137, 139-140.
    - loess; 51-56.
    - rubble; 56-64.
    - sand; 49-51.
    - shale-fragment slopes; 64-67.
    - surface features; 67-74.
  - gravel; 122, 123, 127, 128-129.
  - terraces; 13, 77, 79-80, 83, 86, 88-89, 99-100, 103-107, 108-114, 116-117, 122-131.
- pine; 133.
- pitted outwash plain; 87.
- plant fossils; 14, 132-134, 138.
  - cedar; 132.
  - cypress; 138.
  - fir; 133.
  - hemlock; 133.
  - larch; 132.
  - pine; 133.
  - pollen; 133.
  - spruce; 132, 133.
- Pleistocene floods; 9-10, 77, 81-83, 94, 96, 105, 138.
- Pocono; 20, 68, 69, 74.
- podsolic soil; 32, 42, 46, 47.
- pollen; 133.
- polygenetic soils; 35-36, 40-46.
- Pope soil series; 38.
- Port Huron; 4.
- post-Binghamton soil; 39.
- post-Illinoian soil; 43-45.
- post-Olean soil; 39-42.
- post-Valley Heads soil; 38.
- Pottsville; 20, 69.

- pre-Illinoian;
  - soil: 46.
  - terraces; 3-4, 13, 15, 109, 111-112, 118-119, 122, 123, 129-130.
- pre-Olean soil; 36, 43.
- pre-Pleistocene terraces; 122, 123.
- precipitation; 132, 135.
- profile
  - boulder-strewn slopes; 5, 48, 60-61, 67-68, 69, 71.
  - terrace; 8-9, 11, 12, 13, 15, 77, 100, 105-106, 109, 110-111, 122, 131.

Q

- quartzite; 2, 21, 24, 48, 60, 62, 73, 79, 104, 121, 130.

R

- recent soils; 38.
- recessional moraine; 89-90.
- red and yellow soils; 47, 138.
- river erosion; 10, 11, 19, 79, 84, 90, 105, 110, 111, 121, 125, 139-140.
- rock
  - benches; 1, 13, 75, 107, 109, 112, 114-115, 119, 122-123, 125, 126-127, 129.
  - spurs; 90, 101, 110.
  - types
    - chert; 2, 78, 79, 104, 128, 130.
    - coal; 113.
    - conglomerate; 33.
    - diabase; 108, 109.
    - felsite; 24.
    - gneiss; 18, 19, 21, 24, 32-33, 78, 79, 99, 118, 119.
    - granite; 2, 3, 18, 19, 30, 32-33, 78, 79, 99, 109, 110, 113, 117, 118, 119, 122.
    - igneous rocks; 18, 20, 21, 24, 25.
    - limestone; 2, 17, 19, 20, 28, 79, 98, 99, 108, 118, 121, 129-130.
    - metamorphic rocks; 20, 21, 24, 25.
    - quartzite; 2, 21, 24, 48, 60, 62, 73, 79, 104, 121, 136.
    - sandstone; 19, 21, 25, 29, 48, 62, 68, 69, 74, 78, 79, 124, 128.
    - shale; 17, 24, 29, 48, 60, 62, 64-67, 79, 98, 104, 107, 108, 121, 129.
    - siltstone; 2, 19, 21, 28, 29, 34, 79, 104.
    - slate: 115.
- Rose Hill; 66, 66, 104, 125.
- rubble
  - age; 58-59, 60-61.
  - boulder zone; 62-63, 65.
  - composition; 6.
  - glaciated regions, in; 56-59, 96.
  - Illinoian; 27, 61.
  - jointing; 57.
  - mixing; 58, 63.
  - orientation of boulders; 57.
  - origin; 5-6, 56, 57, 65.
  - significance; 29.
  - soils on; 45.
  - thickness of; 5.
  - unglaciated regions, in; 59-64, 67-74.
  - Wisconsin; 27, 59-61, 65.
- rubification; 4, 7, 27, 28, 33, 35, 138, 140.

S

- sand; 1, 6-7, 9, 10, 19, 25, 38, 43, 56, 72, 76, 80, 83, 92-93, 95, 99, 101, 103, 107, 128-129.
- sandstone; 19, 21, 25, 29, 48, 62, 68, 69, 74, 78, 79, 124, 128.
  - weathering; 33-34.
- scour; 80.
- sediment
  - clay, 19, 28, 29, 38, 62, 64, 86, 93, 105, 117.
  - gravel; 5, 9-10, 13, 17, 23-24, 25, 27-28, 28-30, 76, 80, 92, 101, 103-104, 107.
  - peat; 15, 133.
  - sand; 1, 6-7, 9, 10, 19, 25, 38, 43, 56, 72, 76, 80, 83, 92-93, 95, 99, 101, 103, 107, 128-129.
  - silt; 6, 6-7, 9, 10, 19-20, 24, 38, 48, 52-53, 62, 64, 80, 83, 92-93, 99, 103, 105, 107, 113, 115-116, 117, 124, 127, 130, 131.
- shale: 17, 24, 29, 48, 60, 62, 64-67, 79, 98, 104, 107, 108, 121, 129.
  - weathering; 34-35.
- shale-fragment slopes; 64-67.
  - orientation of fragments; 64, 65.
  - sorting; 64.
  - weathering; 66-67.
- Shawangunk; 45.
- significance
  - gravel; 15, 90.
  - loess; 15.
  - rubble; 15.
  - terraces; 13-14, 140.
- silt; 6, 6-7, 9, 10, 19-20, 24, 38, 48, 52-53, 62, 64, 80, 83, 92-93, 99, 103, 105, 107, 113, 115-116, 117, 124, 127, 130, 131.
- siltstone; 2, 19, 21, 28, 29, 34, 79, 104.
  - weathering; 34.
- Silurian; 34, 62, 67, 69, 71, 104.
- size of blockfields; 73.
- slate; 115.
- slip-off slope; 90.
- slope;
  - ice-front; 25-26.
  - terraces; 77-78, 90.
- snow line; 132.
- soils;
  - age; 38-46.
  - buried; 36, 63, 117.
  - classification; 35-38.
  - composite; 39-44, 47.
  - development; 7.
  - fossil; 36, 63, 117.
  - lateritic; 32.
  - leaching; 4, 42, 47.

- monogenetic; 35, 38.
- on boulder-strewn slopes; 6, 45, 72.
- on dune sand; 49.
- on glacial deposits; 38-45.
- on gravel; 38-40, 45-47.
- on loess; 55-56.
- on rubble; 45.
- on sand; 38.
- on terraces; 99.
- oxidation; 42, 47, 53.
- podsolic; 32, 42, 46, 47.
- polygenetic; 35-36, 40-46.
- post-Binghamton; 39.
- post-Illinoian; 43-45.
- post-Olean; 39-42.
- post-Valley Heads; 38.
- pre-Illinoian; 46.
- pre-Olean; 36, 43.
- recent; 38.
- red and yellow soils; 47, 138.
- series:
  - Barbour; 36.
  - Chenango; 40, 54.
  - Dekalb; 38.
  - Elk; 37, 45.
  - Genesee; 36.
  - Gilpin; 38.
  - Holston; 38, 46.
  - Huntington; 36, 38.
  - Lackawanna; 22.
  - Manor; 59-60.
  - Moshannon; 36, 38.
  - Pope; 38.
  - Volusia; 22, 38.
  - Wheeling; 99.
  - Wooster; 40, 59.
- zonal development; 46-47.

Somerville peneplain; 3, 76, 107, 112-113, 114, 115, 119.
sorting of gravel; 9-10, 81, 83, 92, 93-94
splitting, frost; 49, 67-68, 73-74.
spruce; 132, 133.
spurs, rock; 90, 101, 110.
stagnation, zone of; 86, 92, 97, 138.
storm paths; 13, 135, 136-137, 138.
structure of blockfields; 73.
subglacial till; 22-23.
sumac; 132.
Sunderland; 119-120.
superglacial till; 22-23.
Susquehanna River terraces; 108-120.
- Binghamton; 110, 113-114, 116-117.
- delta; 120.
- Early Illinoian; 109, 111, 114, 118.
- height; 109-112, 114-115.
- Highspire; 109, 111, 118.
- Late Illinoian; 109, 111, 114, 118.
- Mankato; 109, 113, 116.
- Olean; 110-111, 114, 117-118.
- Paxton; 112, 119, 123.
- profile; 110-111.
- rock benches; 109, 112, 114-115, 119.
- Valley Heads; 110, 113, 116-117.

T

Talbot; 120.
Tazewell (see Binghamton)
temperature, air; 131-132, 135-136.
terminal moraine
- Binghamton; 19, 86.
- Illinoian; 26-28, 28-30, 113, 114.
- Olean; 25, 97.
- Valley Heads; 81

terraces
- age; 15-17, 100.
- Binghamton; 77, 81-83, 86-89, 99, 101, 103, 106, 107, 110, 113-114, 116-117, 123, 124, 127, 131.
- composite; 36, 101, 105-106, 116-117, 123, 124, 125, 126.
- cross-section; 11-12.
- definition; 1.
- Early Illinoian; 109, 111, 114, 118, 123, 126, 128-129.
- height; 1, 10-11, 11, 77-78, 79, 81, 81-83, 84, 86-87, 91, 92, 93, 95, 96, 99, 100-101, 107, 109-112, 114-115, 122-123, 123, 124, 125, 126.
- Highspire; 109, 111, 118.
- Illinoian; 84, 99, 101-103, 104, 107.
- Juniata River; 120-131.
- kame; 25, 86-87, 91-97, 101, 104.
- Late Illinoian; 109, 111, 114, 118, 123, 125-126, 127, 128-129.
- Locust Run; 123, 129-130.
- Mankato; 13, 15, 77, 79-80, 99, 100, 103, 107, 109, 113, 116, 123, 123-124.
- methods of study; 10-13, 77-78.
- Mexico; 123, 129.
- Mount Pleasant; 123, 130.
- North Branch, Susquehanna River; 75-97.

Olean; 25, 77, 83-84, 90-97, 99, 101, 103-104, 105, 107, 110-111, 114, 117-118, 122, 124-125, 127-128.
- origin; 1, 6, 10, 13, 77, 79, 95-96, 122, 122-123, 125-126, 139.
- Paxton; 112, 119, 123.

periglacial; 13, 77, 79-80, 83, 86, 88-89, 99-100, 103-107, 108-114, 116-117, 122-131.

profile; 8-9, 11, 12, 13, 15, 77, 100, 105-106, 109, 110-111, 122, 131
- rock spurs; 90, 101, 110.
- significance; 13-14, 140.
- slip-off slope; 90.
- slope; 77-78, 90.
- soils; 99.
- Susquehanna River; 108-120.
- Valley Heads; 77, 81, 89, 99, 100, 103, 105-106, 107, 110, 113, 116-117, 123, 124.
- valley train; 9, 77, 81-83, 84, 87-88, 90, 99, 139.
- Vandyke; 123, 130.

  West Branch, Susquehanna River; 97-107.
terracettes; 80.
thickness of rubble; 5.
till; 6, 11, 14-15.
  Binghamton; 19-20.
  Illinoian; 28.
  Olean; 21-23, 25.
topography
  Binghamton glacial; 15, 86.
  dune sand; 49.
  Illinoian glacial; 17, 27, 28-30.
  Olean glacial; 15, 89-90.
trail; 65, 68-69.
transportation of gravel; 1, 4-5, 9-10, 80, 84, 95-96, 109.
tundra; 137-138, 140.
Tuscarora; 45, 60, 69, 71, 73, 104.

U

unglaciated regions, rubble in; 59-64, 67-74.

V

Valley Heads terraces; 77, 81, 89, 99, 100, 103, 105-106, 107, 110, 113, 116-117, 123, 124.
  terminal moraine; 81.
valley train
  gravel
    defined; 23.
    lithology; 78-79, 99, 103-104, 113.
  terraces: 9, 77, 81-83, 84, 87-88, 90, 99, 139.
Vandyke terrace; 123, 130.
Volusia soil series; 22, 38.

W

water, quality of; 2.
weathering; 4, 11, 30-35.
  blockfields; 73, 74.
  depth; 30-31, 32-33.
  glacial deposits
    Binghamton; 15, 19.
    Illinoian; 17, 26.
    Olean; 15.
  gravel; 17.
  pebbles; 32-35.
    chert; 35.
    conglomerate; 33.
    granite; 32-33.
    quartzite; 33.
    sandstone; 33-34.
    shale; 34-35.
    siltstone; 34.
  rubification; 4, 7, 27, 28, 33, 35, 138, 140.
  shale-fragment slopes; 66-67.
  zones; 31-32, 33-35.
wedges, frost; 53.
West Branch, Susquehanna River; 97-107.
Wheeling Soil Series; 99.
Wicomico; 119.
Wills Creek; 104, 107.
winds; 136.
Wisconsin; 3-4, 13, 15, 17-19.
  loess; 126.
  rubble; 27, 59-61, 65.
Wooster soil series; 40, 59.

Z

zone
  boulder; 62-63, 65.
  of glacial stagnation; 86, 92, 97. 138
  of weathering; 31-32, 33-35.
  periglacial; 137.
  soil; 46-47.

JUN 1953